AKADEMIYA NAUK ARMYANSKOI SSR

EXTRATERRESTRIAL CIVILIZATIONS

Edited by G. M. Tovmasyan

CASE FILE

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EXTRATERRESTRIAL CIVILIZATIONS

(Vnezemnye tsivilizatsii)

Proceedings of the First All-Union Conference
on Extraterrestrial Civilizations and Interstellar Communication
Byurakan, 20 — 23 May 1964

Edited by G. M. Tovmasyan

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Table of Contents

COSMIC LINGUISTICS

iv

ANNOTATION

This volume contains the proceedings of the First All-Union Conference on Extra-
terrestrial Civilizations and Interstellar Communication, held at the Byurakan
Astrophysical Observatory of the Armenian Academy of Sciences in May 1964.

The basic premise of the conference was the multiplicity of inhabited worlds.
In the light of this assumption, the participants discussed the possibility of existence
of alien civilizations at various levels of development and considered the means for
establishing interstellar communications. It was agreed that the best course would be
to start simultaneous reception and transmission of radio signals. Artificiality criteria
differentiating the multitude of natural radio signals received by radio-astronomic
equipment from space from artificial radio signals sent by technically advanced alien
civilizations were discussed in considerable detail. The problems of cosmic linguistics
were also touched upon at the conference.

PREFACE

The existence and the evolution of intelligent life in the Universe is of enormous scientific and philosophical importance. At a certain stage, when the question of interstellar communications is raised, this topic inevitably acquires exceptional sociological significance.

Modern astronomical equipment enables us to probe a sphere with a radius of nearly 10 billions* of light years in space. This visible part of the Universe contains some 10^{10} galaxies and approximately 10^{20} stars. Within this region of space, matter occurs in the same forms which are known to us on Earth. All the findings of modern astrophysics indicate that the fundamental laws of nature hold true within the confines of the visible Universe and the chemical composition of matter is nearly constant. There are consequently no special reasons for singling out the solar system among the 10^{20} stars in the part of the Universe which is currently accessible to observations. Furthermore, not a single sound argument has been advanced which is capable of disproving the possibility of existence of intelligent life in other planetary systems. According to very crude and hypothetical estimates, one civilization should occur in the Universe each $10^6 - 10^{12}$ stars. The mean distances between civilizations are therefore not less than a few hundreds of light years, and possibly even thousands of light years.

The recent advances in astronomy and biology permit a reasonable, scientific approach to the question of the multiplicity of inhabited worlds in the Universe. The present-day state of radio engineering makes long-range interstellar communication quite feasible. Radio astronomers have become highly proficient in the detection and analysis of radio sources in space, up to distances of billions of light years. The development of cybernetics, general theory of language, and modern mathematical techniques provide the necessary tools for tackling the general features of information transmission and reception between civilizations and for an objective analysis of coded signals; the subject of cosmic linguistics is also beginning to be approached scientifically.

To sum up, communication with extraterrestrial civilizations, which has remained unfeasible until lately, now appears to justify the application of concerted scientific and technical efforts for its realization.

The present volume includes the proceedings of the First All-Union Conference on Extraterrestrial Civilizations and Interstellar Communication. This was the first attempt to organize a comprehensive, all-sided discussion of the problem.

The conference was held in May 1964 at the Byurakan Astrophysical Observatory of the Armenian Academy of Sciences. Academician V. A. Ambartsumyan, Academician Ya. B. Zel'dovich, Academician

* [Throughout this book, 1 billion = 10^9.]

V. A. Kotel'nikov, Corresponding Member of the USSR Academy of Sciences
A. S. Pistol'kors, Corresponding Member of the USSR Academy of Sciences
V. I. Siforov, the outstanding scientists N. L. Kaidanovskii, B. V. Kukarkin,
D. Ya. Martynov, V. S. Troitskii, S. E. Khaikin, I. S. Shklovskii, and many
other representatives of various scientific institutes from Moscow,
Leningrad, Erevan, Gorkii, and Novosibirsk took active part by presenting
enlightening papers to the conference or participating in the lively dis-
cussions that followed.

This collection will be of considerable interest for scientists and
engineers specializing in the fields of astronomy, radio astronomy, radio
communication, and other related subjects. It can also be enjoyed by laymen.

INTRODUCTION

V. A. AMBARTSUMYAN

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This conference is devoted to the problem of extraterrestrial civilizations (EC). It is a first attempt to organize a comprehensive, all-sided discussion of the subject. The problem under consideration is one of those which are still in the stage of formulation. The very statement of the problem unfortunately remains not clear to a considerable degree.

We all feel, however, that science, and in particular Soviet science, cannot bypass the question of the existence of intelligent life elsewhere in the Universe and the problem of establishing interstellar communications. If this conference succeeds in defining correctly at least some of the problems pertaining to EC and in delineating the first steps to be taken toward the solution, or in other words if it succeeds in making the situation less amorphous than it is now, we shall be able to say that the conference has justified itself. Anyway, I do hope that after this conference we will all agree that it was not premature.

It seems to me that the problem of extraterrestrial civilizations can be divided into three parts: (a) the existence of EC in the light of the astronomical notions on the evolution of life and civilizations in remote planetary systems; (b) the detection of EC and communication between them, primarily the problem of establishing communication between the Earth civilization and the alien intelligences; (c) the problem of language and the transmitted information. The last problem should of course be approached differently for one-way and two-way communications. It is obvious that only one-way communication is possible over large interstellar distances exceeding, say, thousands of light years (and this without mentioning intergalactic communications); the scope of communication and the nature of the transmitted information are inherently limited by this restriction.

Before we go into the question of the existence of alien civilizations in remote planetary systems (we are confident that no other advanced civilization, except the Earth civilization, exists in our planetary system), we should briefly consider the probable material systems which may conceivably act as the carriers of civilization.

Ordinarily, a carrier of civilization is a society of more or less similar individuals, each capable of receiving, accumulating, storing, processing, and transmitting information. It is further assumed that these individual members are biological organisms. The communication with EC is thus regarded as communication with societies of this kind.

Other EC carriers, however, can also be imagined. Preliminary considerations show that the very existence of other carriers cannot be rejected a priori. In principle, an extraterrestrial civilization may be deposited in a cybernetic system which is not made up from individual, autonomous parts, each in itself capable of acting as a carrier of civilization. A system consisting of autonomous, but highly specialized cybernetic machines and automata is another example of an EC carrier which is entirely different from human society.

We do not propose to speculate any further on the possible models of EC carriers. It suffices to observe that biological evolution will initially lead to systems consisting of individual members, but the biological stage can be succeeded by a phase favoring the arisal of new, different carriers.

At the present level of our knowledge it seems, however, that biological evolution is a prerequisite for the development of a civilization, regardless of the peculiar forms the civilization may take later on. The question of astronomical proof of the existence of EC is thus primarily a question of the range of astronomical conditions which are adequate for the evolution of life and the subsequent gradual evolution of intelligent beings and civilization. If this range can be determined, the already available data of stellar astronomy will be used as a basis for serious statistical calculations on the frequency of occurrence of favorable conditions. The main link for these calculations is unfortunately missing: we do not know what the general structural regularities of planetary systems are, since we are acquainted only with our solar system. It is quite possible that the regular features of our planetary system (planetary orbits which are approximately coplanar and nearly circular, orbital radii varying according to the Bode-Titius law) are characteristic of the Sun's planets only or, conversely, that they are particular manifestations of some more general regularities.

The situation will be considerably improved if the accuracy with which the proper motions of the nearby stars are measured is raised at least by one order of magnitude. Anyway, the solar system has already provided us with essential data on the possible diameters of planetary orbits and the sizes of individual planets, which is highly significant for visualizing the probable conditions near other stars.

What are the main astronomical parameters which are prerequisite for the evolution of life and civilization? When we say life, we of course mean life processes having the same chemical basis as on Earth.

In our opinion, the fundamental parameters are the following: (a) the stellar constant, which is the analog of the solar constant for the particular planet: it characterizes the energy flux per unit surface area of the planet; (b) the color temperature of the star: this factor has an enormous significance, since photochemical processes are particularly essential for the evolution of life; (c) the age of the star.

Besides these parameters, we should also take account of some additional factors which, though less significant in general, may prove to be quite decisive under certain conditions. Under this category we have, e.g., (a) the inclination of the planet's equator to the orbital plane, (b) the period of planet's rotation about its axis, (c) gravitational acceleration, (d) whether the primary is a variable star or one of the components of a binary system. High variability is apparently a factor which inhibits normal evolution of life.

In conjunction with astronomical parameters, we must consider various planetographic and planetochemical characteristics as well. The presence of an atmosphere, its composition and thickness are obviously of paramount importance. The sea has played a significant role in the evolution of life on Earth, so that the presence or the absence of oceans may prove critical. Finally, local topography, the size of the continents, and other factors pertaining to dry-land areas may influence the initial stages in the development of a young civilization.

We have no doubt whatsoever that life and civilizations exist on a multitude of celestial bodies, but we must go in some detail into the question of possible technological disparity between these civilizations. Although the Earth civilization, in the broad sense of the word, is a few tens of millennia old, the modern technological civilization has its origin no more than two hundred years in the past. It is moreover highly significant for the problem under consideration that the present-day notions on stellar systems, i.e., the conceptual approach which has suggested the multiplicity of inhabited worlds, have arisen and developed during the last two centuries. And yet, the ages of planets may differ by as much as millions of years. Hence the apparent conclusion that different civilizations in the Universe may differ by millions of years in their respective development. It seems that the Earth civilization is not yet past the diapers age, and that there should be enormous disparity between EC.

The problem of communication between EC is therefore essentially a problem of communication between civilizations on entirely different levels of development. Everybody will agree that, starting at a certain point, the level and the nature of a civilization changes rapidly, undergoing radical transformations even during a single century. The changes which may occur in hundreds of thousands and millions of years are therefore hardly imaginable.

In practical terms, our aim is therefore to obtain rational technical and linguistic solutions for the problem of communication with extra-terrestrial civilizations which are much more advanced than the Earth civilization. The papers to be presented to this conference all deal with various aspects of this problem.

MULTIPLICITY OF INHABITED WORLDS AND THE PROBLEM OF INTERSTELLAR COMMUNICATIONS

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The title of this paper is a statement of a problem whose origin goes many centuries back into the past (see my book "Vselennaya, zhizn', razum"*, Moskva, Izdatel'stvo AN SSSR. 1962). But it is only recently that this problem, which is clearly one of the most important that have ever faced humanity, has begun to receive legitimate scientific attention.

This can be attributed to the exceptional achievements of astrophysics, radio astronomy, cybernetics, molecular biology, and the related sciences in the last ten-twenty years. This problem became particularly topical with the development of special scientific disciplines on nature and society. The publication of over 100 works dealing with this problem during the last 3—4 years is by no means a matter of chance. Collections of papers are being published, special conferences are being held. We are witnessing the inception of a new science, which occupies a boundary position between astrophysics, biology, engineering and even sociology. This new science remains unnamed for the time being, but it has already attracted the keenest attention of both specialists and laymen.

What were the actual achievements of modern science which made possible this recent development in the approach to the problem of the multiplicity of inhabited worlds in the Universe and the possibilities of communication between them?

1. It has been established that with a high degree of probability planetary systems are a very common occurrence in the Galaxy. The indirect, though fairly convincing, arguments pertaining to the peculiarities in the rotation of stars of different spectral classes (for more details, see the above cited book of mine, which is henceforth designated by the symbol /1/) have recently been supplemented by a direct piece of evidence. Van de Kamp, the well-known American authority on photographic astrometry, found last year that one of the nearest stars — "Barnard's flying star" — is accompanied by an invisible satellite of unprecedentally small mass. Measurements of vanishingly small fluctuations in the proper motion of Barnard's star (with an annual amplitude of 10", the greatest among all the known ones) led to the conclusion that the mass of the perturbing invisible satellite was no more than 1.5 times the mass of Jupiter; a fairly eccentric orbit was determined with a semimajor axis of 4.4 astronomical units and an orbital period of 24 years. Barnard's star itself is a red dwarf of spectral class M5, its radius is 1/6 of the

* ["The Universe, Life, and Intelligence"; also see the English version of this book, I. S. Shklovskii and C. Sagan, "Intelligent Life in the Universe". — Holden-Day Inc. 1966.]

Sun's radius and its mass is 0.15 of the solar. A body with 1.5 times the mass of Jupiter cannot become luminous, as its interior temperature is too low — a few hundreds of thousands of degrees. Thermonuclear reactions, which are the main source of stellar energy in the Universe, cannot occur there. This body is in all probability a giant planet, not unlike our Jupiter.

The fact that one of the nearest stars has a planet points to the enormous abundance of planetary systems in the Galaxy, and this is the greatness of van de Kamp's discovery. It should be borne in mind, however, that the orbit of the giant planet moving around Barnard's star is highly elliptic, while the orbits of nearly all the planets in the solar system, those of the giant planets Jupiter and Saturn included, are almost circular. It is not clear whether this difference can have a substantial qualitative influence.

Anyhow, the multiplicity of planetary systems in the Galaxy appears to be an established fact to a high degree of probability.

2. The recent advances in molecular biology, biophysics, and bio-chemistry, which for the first time have lifted the veil off the enigma of life and its origin, are also of great significance in connection with the problem under consideration. Without these advances in biological and chemical sciences, we could not even begin to understand the origin of life on Earth and other planets. We must stress, however, that the path to the solution of this problem is still very sketchy. We still have to find to what extent the evolution of life on Earth is a r e g u l a r phenomenon, and this clearly requires detailed knowledge of the pre-geological period of the evolution of our planet. Planetary cosmogony should be extended at least to the stellar level, and we are unfortunately still far from this goal. Some advances, however, have been reported in this field also; for example, the decisive role of electromagnetic processes has been established.

3. The extraordinary achievements of radio astronomy in the recent years are of decisive significance for the problem of establishing contact with extraterrestrial civilizations. In this connection we should emphasize the importance of the technical revolution in radio physics which emerged with the advent of quantum amplifiers of radiation (masers) and the building of antenna arrays of large equivalent surface. All this substantially increased our radio-physical potential, and in principle radio communications over distances of a few tens of light years no longer seem improbable. A sphere of this radius contains several hundreds of stars, but already in the next decade the ultimate communication range will in all probability increase by another order of magnitude and thus reach the quite substantial distance of nearly 100 parsecs. A sphere of this radius contains hundreds of thousands of stars.

4. Cybernetics will play a leading role in the problem of establishing communication with extraterrestrial civilizations. Search for optimal signal characteristics and the problem of automata require the application of cybernetic concepts and methods. Modern cybernetics has already raised the question of new artificial life forms (artificial intelligence included). The subject of artificial intelligence may prove to be of unique importance as we go on with our researches.

5. The conquest of space is the main reason which stimulates the current interest in extraterrestrial intelligences. The inexorable and systematic expansion of humanity into the outer space is in itself a vivid proof of the existence of intelligent life. This process should by right be

considered as a qualitatively new stage in the development of humanity.
In no more than five years, the sphere of human activity has increased
by a factor of thousands. And yet, we are witnessing the very first stage
of this process, and it is very difficult to imagine all the sociological
consequences and the radical changes to be expected during the next few
centuries. Unrestrained expansion of human activity throughout the entire
near-solar space is an inevitability, culminating in the creation of an
artificial biosphere some 10 −15 orders of magnitude greater than the
natural habitat of man. Some important consequences of this regular
process will be discussed in the following. At this stage, I would only
like to quote from one of Sir Arthur Conan Doyle's books, "Through the
Magic Door": "... Anyway, no one understands the true significance of the
age one lives in. Fancy, for example, the Old Masters seeking their
subjects in inn parlours, or St. Sebastians, while Columbus was discovering
America before their very faces."

The tangible possibility of establishing the existence of life on the
nearest planets by means of direct biological experiments has the most
immediate bearing on the problem being considered. It is hoped that the
enigma of life on other worlds will be solved in the next five years. If,
for example, experimental findings establish the existence of at least
some primitive life forms on Mars, where the objective conditions are
quite rigorous, this will constitute a factual corroboration of the notion
that life, as a higher form of the existence of matter, r e g u l a r l y evolves
on planets. There are probably billions of planets in the Galaxy, located
at adequate distances from their respective primaries (F8-K0 stars),
where the conditions are much more favorable than on Mars. For example,
according to the latest American and Soviet observations in the infrared,
the atmospheric pressure on Mars is approximately 1/50 of the pressure
on Earth. Even if it turns out that the primitive martian life forms are of
terrestrial origin, having been imported from the Earth in the form of
spores, this will not detract from the significance of the discovery.
Incidentally, the critique of the basic concepts of panspermia should be
reconsidered in this connection. It has been proved that the simplest
microorganisms and their spores withstand and adapt themselves to
enormous radiation doses. Panspermia should not be regarded as a
philosopher's "bogey", as long as the antiscientific notion of the eternity
of life is avoided. The Universe is evolving, and the early stages of
evolution of necessity preclude the very possibility of life. In my opinion,
it is highly ridiculous to suggest that "autonomous" development of life on
planets is a materialistic proposition, while "pollination" with spores
from outer space is an idealistic concept. Only scientific arguments —
primarily experimental work and observations — will resolve this
contradiction.

The following question is also of great importance: i· i n t e l l i g e n c e
an inevitable consequence of the long and tortuous evolutionary process
of life forms? In my opinion, this is by no means so. Moreover, we
should take account of the fact that the probability of i n t e l l i g e n t life
forms developing on any given planet is exceedingly low. Another problem
of cardinal significance is the d u r a t i o n of the psychozoic era (the age
of intelligent life) on any given planet (we denote this duration by t). Here
we are on fairly uncertain ground. Most of the scientists abroad, as well
as many of the Soviet researchers, think that the age of intelligence is

definitely shorter than the cosmogonic time scale ($T \sim 10^9 - 10^{10}$ years).
We should emphasize that this particular question is by no means of purely
academic interest. A mathematical relation expressing the mean distance
between two "contemporary civilizations" can be derived:

$$d = 5.2 \left(\frac{T}{t}\right)^{1/4} \text{parsec}.$$

The dependence on t is weak, but given $t \sim 10^5 - 10^6$ years, we find
$d \sim 100$ parsec even under the most optimistic assumptions (billions of
planetary systems in the Galaxy, with intelligent life evolving on each
planet).

There is, however, a possibility that some civilizations, having
reached a highly advanced level, will find themselves past the inevitable
crises and internal contradictions which plague the younger civilizations. The
evolutionary time scale of these quiescent civilizations may be considerably
larger, approaching the cosmogonic scale. Incidentally, I should stress
that even 10^5 years is an enormously long period for the t e c h n o l o g i c a l
stage in the life of a civilization; the consequences may turn to be quite
unpredictable. This point will be discussed in some detail in the following.

We now summarize the starting data which are required for a scientific
analysis of the possibility of establishing contact between planetary
civilizations. In the most favorable case, the civilizations occur at inter-
stellar distances, i.e., at distances of $3 - 5$ ps. This comparatively high
density of civilizations is little probable, as it ignores a great multitude
of restricting factors. Moreover, the optimistic estimate is apparently
inconsistent with the negative result of the recent observations under
Project Ozma.

1. The minimum average distance to the nearest alien civilization is
probably ~ 300 ps. This estimate is arrived at on the basis of the following
assumptions: (a) all the stars of spectral classes F8-K0 are accompanied
by planets, and at least one planet in each system can, and actually does,
sustain life; (b) the product $\alpha \frac{t}{T} \sim 10^{-5}$, where α is the probability that
evolving life forms will become intelligent, t the duration of the psychozoic
era, T the age of the primary. There is however a possibility that d will
be much greater than 300 ps. Furthermore, in principle there is nothing
to suggest that our civilization is not unique in the entire Galaxy, though
of course not in the entire Universe.

As soon as we accept the premise that the Earth civilization is not the
only intelligent civilization in the Universe, we are facing the problem of
establishing communication between civilizations.

The following types of contact between civilizations are possible:

(a) Interstellar trips, in particular, launching of automatic cybernetic
space probes.

(b) E l e c t r o m a g n e t i c signals.

The first method is apparently not promising (at least not for the
purpose of establishing actual contact). Not only that it is unfeasible at
the present-day level of technological development, it is without any
future (see von Hoerner's paper in the book "Interstellar Communication").

8

Irrespective of what sicence-fiction writers think, interstellar photon rockets moving with relativistic velocities will apparently never be built. Each generation characteristically overestimates its technical abilities. I would like to remind you that the possibility of flying to the Moon in a ship propelled (of all things) by a steam engine was considered quite seriously in the 19th century. Still earlier, some science-fiction writers hoped to make this trip in a balloon! Now we are again witnessing blatant overestimation of the inherent capabilities of jet propulsion. This is an ideal solution for interplanetary flights and for the future conquest of the near-solar space. Moreover, rockets can be used as a powerful means for gradual expansion of civilizations from one planetary system to another, nearby system. In the latter case, however, the rockets will travel at nonrelativistic velocities. But communication between different civilizations inhabiting planetary systems of different stars cannot be established even by photon rockets. Once we accept this limitation, we have to start looking for other possible solutions.

The idea of establishing interstellar communications by means of electromagnetic transmission channels was first advanced by Cocconi and Morrison in 1960. Their paper was in fact the first stimulus for all that has been done in this field since. A detailed analysis of the problem indicates that radio waves apparently constitute the most convenient, economic, and promising solution. Centimeter and the short decimeter wavelengths constitute the optimal region of the entire radio spectrum. Cocconi and Morrison suggested communication at 21-cm wavelength (see /1/). Soon after the publication of their paper, Drake tried to detect artificial signals from the nearest stars which met the basic requirements — ϵ Eridani and τ Ceti (Project Ozma). It seems to us, however, that Project Ozma has been doomed from the very start, and this for the following reasons:

(a) It is assumed that civilizations may occupy the nearest stars, which is highly improbable. If now $d \sim 100 - 300$ ps, beamed communication is hardly feasible, since there are at least 10^5 stars at these distances.

(b) In our opinion, the main deficiency of Cocconi and Morrison's idea and of its realization by Drake is in the assumption that the extraterrestrial civilizations are approximately on the same technological level as the Earth civilization. An inevitable conclusion which follows from this assumption is that the power of the receivers and the transmitters available to the alien civilizations is roughly the same as that of our equipment. But this proposition is inherently fallacious. It is well known that the time scale for the technological development of civilizations is exceedingly short. Consequently if there are civilizations in the Universe, they should greatly differ in the degree of their development. The great majority of civilizations should be technologically much more advanced than we are. We are only infants as far as science and technology are concerned. Radio communication, for example, was discovered less than 70 years ago. Nuclear energy was first released less than 20 years ago. Thermonuclear fusion has not been harnessed yet.

Therefore, in analyzing the problem of interstellar communications, we should take account of the exceedingly high technological level of alien civilizations immediately in the "zeroth approximation". This approach is the outcome of practical requirements, since the technical aspects of projects depend on the starting premises. The only way to estimate

9

the technical level of alien civilizations is by extrapolating the technological development of our civilization. This is a difficult and highly uncertain course. However, without this extrapolation no progress can be made. Our task here is simplified to a certain degree since we are not expected to form a detailed picture of the advanced civilizations. We only have to evaluate the rates and the scales of intelligent activities.

The short time scale for technological development is of decisive significance. It should be remembered that science and technology, in the modern sense of the word, arose no more than 10 generations ago. Galileo was the founder of mechanics, and his contributions mark the beginning of modern science and technology. But now, a mere 350 years later, technology is a factor on the cosmic scale: its scope has already overstepped the humble bounds of the Earth. I want to give two examples.

(a) As a result of television broadcasts, etc., Earth is radiating approximately 1 watt per c/s at meter wavelengths into space (there are a few thousands of TV transmitters on the Earth with a mean power of ~ 20 kW). The brightness temperature of the Earth at meter wavelengths is nearly 10^8 degrees.

In the solar system, the Earth is thus inferior only to the Sun where the intensity of radio emission at meter wavelengths is concerned. It radiates 10^6 times more power than either Venus or Mars.

(b) High-altitude nuclear explosions have entirely distorted the original radiation belts, which could have been once regarded as a cosmic characteristic of the Earth. This distortion is apparently permanent; it will hardly "dissipate".

Man does not always fully realize the true consequences of his actions. I would like to call your attention to still another aspect of human activity which may be of decisive significance for our problem. I am referring to energy production and the fantastic rate of its growth. At present, the Earth civilization produces approximately $3 \cdot 10^{19}$ erg/sec. The energy production is now doubled each 20 years. Assuming a constant rate of growth for the next few centuries, we see that in another 200 years we will be producing $3 \cdot 10^{22}$ erg/sec or $\sim 1\%$ of the solar energy flux reaching the Earth. This may even occur earlier if the growth rate of energy production is accelerated. Further increase in energy production will of necessity alter the heat regime of the Earth. We must not forget, of course, that solar energy will be harnessed before that, but we can hardly expect that more than $\sim 10\%$ of the entire flux of solar energy will ever be utilized. Anyhow, in less than 300 years, all this will crystallize into a very acute problem. Some foreign authors are of the opinion that further growth of energy production will have to be restrained and strictly forbidden by legal and administrative means. Powerful energy-producing systems will probably be moved to the outer space, where humanity will really spread its wings (though again within limits).

This process of moving high-power aggregates into the outer space will begin much earlier because of the considerable radiation hazards involved when these installations are erected on Earth; another factor which will obviously aid this trend is that, as we advance into the future, new experiments will have to be staged and new kinds of production processes initiated, all of which require enormous space not available on Earth. Some daring, but quite realistic projects calling for space-stationed bases have already been outlined. It suffices to mention the Kardashev–Slysh

project of setting up a radio interferometer on an artificial Moon satellite.
It is particularly for these reasons that the pioneering space research
and the first steps of man in space are of universal historical significance,
which supersede by far the great achievements of Columbus and other
courageous travelers of the Age of Discoveries.

When humanity eventually starts harnessing and transforming the
solar system, its energy and material resources will increase
immeasurably. The figure of $\sim 10^{33}$ erg/sec is not the limit, since
part of the planetary mass can also be used in fueling thermonuclear fusion
reactions. Various criteria seem to suggest that humanity will conquer
and transform the solar system in a few thousand years, anyway in a
period of less than 10^4 years, which is vanishingly small in comparison
to the cosmic time scales. This leads to a very important conclusion:
if civilizations do exist in the Galaxy, many, if not most, of them will
have reached by now a technological level characterized by availability
of energy resources of the order of 10^{33} erg/sec and by radical trans-
formation and artificial re-making of "their" planetary systems. Artificial
biospheres with linear dimensions of $\sim 10^{13} - 10^{15}$ cm are quite probable.
We do not intend to go here into various particular projects for the
conversion and re-arrangement of planetary systems which have been
proposed in the literature (e.g., Dyson's sphere /1/). This is quite
besides the point. We are only concerned with an estimate of the intrinsic
energy resources and abilities of these "supercivilizations".

At this point we should ask whether the confines of a planetary system
actually set a limit to the development and expansion of intelligent life.
I think not. There can be no limit to the abilities of that highly organized
form of existence of matter which we call life.

In principle, the following situation may arise. Having conquered
the original planetary system, the highly advanced civilization will start
"diffusing" to the neighboring stars. These new stars need not even be
accompanied by planets. The intelligent beings under consideration have
fully mastered the technique of creating an artificial biosphere. The
conversion of the space surrounding the neighboring star into a proper
habitat may take several millennia. The transportation of materials, etc.,
will take a few centuries, i.e., less than the time for environmental
adjustment. The newly "organized" biosphere will in turn act as an
additional center of diffusion. This diffusive process, if carried out
according to some coordinated program, can be expected to encompass
the entire Galaxy in a few tens of millions of years. The actual time
scale will probably be shorter, since the expanding supercivilizations
develop qualitatively, as well as quantitatively.

Once this project is materialized, the energy production can be raised
to $\sim 10^{43}$ erg/sec or even more. Significantly, there are no apparent
reasons which indicate that civilizations in other galaxies could not evolve
in the same way. Hence the second conclusion: other civilizations
conceivably exist which have harnessed energy resources of $\sim 10^{43}$ erg/sec
and which have built an artificial biosphere of the size of a planetary
system, i.e., of the order of $10^{22} - 10^{23}$ cm.

We are far from being convinced that the above sketch is the inevitable
course of evolution of each and every civilization. It must be clear to all
of us that serious crises are continually encountered by the evolving

civilizations. One of these crises may even prove to be fatal. Some of the crises and internal contradictions of the future can be visualized even now.

(a) Self-destruction as the result of a thermonuclear holocaust or, in general, a discovery leading to unexpected and uncontrollable consequences.

(b) Genetic failure.

(c) Over-production of information.

(d) Limited brain capacity of the individuals: this may result in over-civilization and eventual degeneration.

(e) A crisis connected with the creation of artificial intelligence.

Other crises and dilemmas, which at present remain unconceivable to us, may of course also arise.

Finally, a civilization may choose not to follow the path of "quantitative" expansion. It will freeze the energy resources, forbid uncontrolled space flight, and then concentrate on entirely new interests leading to a kind of "qualitative perfection".

In my opinion, this situation is equivalent to degeneration. But suppose for a minute that this is not so. In this case, I do hope that no one will rise to maintain that this "loss of interest" is the only possible outcome of evolution.

The questions being discussed are not quite so scholastic as may appear at a first glance. The existence of supercivilizations with energy resources of $\sim 10^{33}$ and even 10^{43} erg/sec is of decisive significance for establishing interstellar radio communications (which is the actual subject of this conference). This point will become obvious from N. S. Kardashev's paper.

There is still another question to be discussed: will these supercivilizations actually send radio signals in order to establish contact? This is a somewhat rhetorical question. We should remember that our and other similar civilizations, which are still at the embryonal level of development, are of enormous interest to a supercivilization. After all, our scientists and laymen show interest not only in prehistoric society, but also in the community life of ants, bees, etc. The intricate details of the structure and organization of the simplest microorganisms arouse no less interest.

Radio communication is of comparatively recent origin. We have to ask ourselves whether radio will remain a decisive factor of communication in the future. The answer to this question is probably in the affirmative, provided that our present-day notions of nature and its fundamental laws are correct. It has been proved already that radio communication is the most economic and informative among all the conceivable means of communication.

Very distant supercivilizations can be detected by objective observations, since the celestial objects related to these civilizations behave quite differently from inanimate matter or possess curious and even unnatural characteristics. We have thus approached the problem of "cosmic wonder" — manifestations of intelligent activity on the cosmic scale which can be observed from afar (see /1/).

This is in short the present-day situation as far as the general problem of extraterrestrial civilizations and interstellar communications goes. We should emphasize that the final decision should be left to experimental work and to regular, systematic observations. Another question can be raised in this connection. Why, say, the problem of thermonuclear fusion has attracted worldwide attention and enormous financial means, while the

problem of extraterrestrial civilizations, whose importance for all aspects of human activity can hardly be overestimated, remains in a rudimentary state to this very day? Is it not true that already now, by allocating sufficient funds (not small, but well within reason), we can make great strides toward the solution of this unique problem? Fusion researchers, whose equipment and research work are fantastically expensive, have never guaranteed to harness thermonuclear forces forthwith and to start producing energy with an acceptable efficiency. They are allowed to solve their physical problems gradually and systematically, approaching the basic goal at some indefinite time in the far future. Is there really a substantial reason why the problem of extraterrestrial civilizations should be considered inferior to the problem of controlled fusion?

In conclusion I would like to stress that for me there could be no greater wonder than a conclusive proof that no "cosmic wonders" exist. Only an astronomer can fully grasp the true meaning of the fact that among the 10^{21} stars comprising the visible part of the Universe ($\sim 10^{10}$ galaxies with $\sim 10^{11}$ stars each) not a single one houses a sufficiently advanced civilization, although the percentage of stars accompanied by planets may be quite high.

DISCUSSION

G. A. Gurzadyan. I do not understand why I. S. Shklovskii has quoted 10^4 years as the lifetime of a civilization on a particular planet or in the planetary system of a particular primary. Why not take a billion years, which is closer to the age of the primary? Insofar as we are unable to fix the reasons and factors, either natural or artificial, which may set a limit to the lifetime of a planetary civilization, the probability of finding alien civilizations on nearby stars should increase markedly. This may substantially modify the considerations presented in I. S. Shklovskii's paper.

I. S. Shklovskii. Civilizations can hardly be expected to have extremely long lives. In 10^9 years civilizations apparently degrade. The ants, for example, have existed for over 200 million years.

Ya. B. Zel'dovich. This is an unfounded point of view. Nobody knows a priori how our society will develop over thousands of years. This uncertainty is particularly pronounced for extraterrestrial civilizations about which our knowledge is exactly nill.

V. A. Kotel'nikov. By all means, don't let us "extinguish" extraterrestrial civilizations. Let us start looking for them.

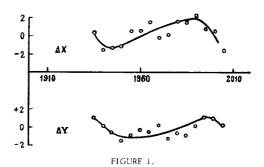B. V. Kukarkin. It would be interesting to consider what information optical astronomy can provide to help us in the selection of objects which may probably have intelligence-supporting planetary systems.

The presence of "invisible satellites", which have been discovered for some of the nearby stars by examining the periodic fluctuations of the luminous primary about the straight line described by the system's center of gravity, may turn out to be a much more reliable criterion for the existence of planetary systems than is currently thought. The current opinion is that many of the characteristics of the "invisible satellites" place them within a category entirely different from that of solar-type planetary systems. Indeed, the derived masses are much greater than the mass of Jupiter, the orbits are noticeably eccentric (this is hardly conducive to the evolution of highly developed organic life forms), and the "invisible satellites" mostly accompany dwarf stars of late spectral classes (mainly of class M, which again seems to preclude the evolution of life on account of the low ambient temperature on the alleged planets). I would like to contradict some of these widespread arguments.

Back in 1951 it was first suggested that the problem of "invisible satellites" cannot be explained as simply as was commonly done (see "Trudy pervogo soveshchaniya po voprosam kosmogonii", p. 352. — Moskva, Izdatel'stvo AN SSSR. 1951). Measurements by the conventional methods of photographic astrometry generally reveal fluctuations of a star about a center of gravity. These fluctuations are attributed to a simple Kepler motion (the two-body problem). In reality, however, there may be a system of several planetoids, and not a single "invisible satellite".

14

The orbital periods of these planets are roughly commensurate, and this inevitably leads to a certain cyclic behavior, reminiscent of beating. This cyclic process is naturally interpreted as the motion of a single body. Furthermore, combination of several circular periodic motions may result in apparent eccentricity.

As an illustration, I would like to show a graph plotting in an arbitrary linear scale the motion of the Sun about the center of gravity of the solar system for a period of 70 years in rectangular coordinates, as is the practice of astrometrists studying the behavior of stars with "invisible satellites". I have artificially averaged position readings for close times, since this is again a common practice in the study of "invisible satellites". The averaging substantially smoothed the fairly pronounced (though highly variable in time) wave which is attributed to the Jovian gravitational perturbation. We see that the individual "normal" points are spread out to a considerable degree, but on the whole they can be said to correspond satisfactorily to a fairly eccentric orbit with a period of nearly 60 years. This resultant effect is easily understood if we remember that Jupiter and Saturn — the two planets of the largest mass in the solar system — have closely commensurate orbital periods. Five Jovian periods amount to 59.315 years, and two periods of Saturn take 58.915 years.

FIGURE 1.

Compare the curve plotting the motion of the Sun with the corresponding curve for Barnard's star, which was mentioned by I. S. Shklovskii in his paper. The spread of the individual points is again comparable with the amplitude of the overall wave. The probability is therefore fairly high that this is also the combined effect of a system of bodies, and not of a single satellite. The same line of reasoning can be applied to other stars accompanied by "invisible satellites".

It should be emphasized that the displacements of a star about the center of gravity are within the present-day accuracy of astrometric measurements. It is only by measuring tens, or even hundreds, of repetitive plates that these fluctuations can be brought out.

Modern astrometry unfortunately uses old-fashioned methods of length measurement (linear scale and micrometer). Furthermore, emulsion graininess and the turbulence of the Earth's atmosphere set a natural limit to the accuracy of measurements. Work in the following directions should therefore be launched most urgently

(1) Development of new techniques of length measurement (by interference, etc.).

(2) Search for alternative methods of measurement of separation between stars which appear to be close in the image plane, b e s i d e s photographic measurements.

(3) Measurements of star separations outside the atmosphere.

If the three problems above are solved successfully, the accuracy of measurements will increase by two or even three orders of magnitude, which is quite sufficient for resolving the resultant curve into the component oscillations. The masses of the individual satellites will probably be smaller than the mass of the hypothetic body whose gravitational perturbation is substituted for the sum of the perturbations due to the several planets. The two main objections (eccentricity of orbit and large mass) are thus eliminated.

"Invisible satellites" have been discovered for some stars of class K, as well as for class M dwarves. There is nothing to indicate that they will not be discovered for Sun-type stars too. Successful solution of the above problems will inevitably facilitate the detection of planetary systems around hundreds of the nearest stars.

Planets can also be detected photometrically. If an imaginary observer on one of the not too distant stars located in the orbital plane of Jupiter starts making systematic photometry of the Sun, he will discover that every 11314.84 days the Sun is attenuated by 0.01 stellar magnitude. This waxing and waning is obviously attributed to the periodic transit of Jupiter across the Sun's disk. The duration of this annular eclipse is no more than three and a quarter days, the ascending and the descending branches taking less than an hour each (the slight brightness variation connected with the limb brightening of the Sun will somewhat distort the flat minimum). On Earth, where atmospheric turbulence and variability of the light absorption coefficient render impossible brightness variation measurements with an accuracy better than 0.01 stellar magnitude, the photometric approach to the detection of planets is pretty hopeless. Outside the atmosphere, however, even present-day electrophotometric techniques permit measurements with accuracies higher by more than one order of magnitude, so that "eclipses" due to the transit of planets can be recorded with sufficient reliability. A suitable program for this search should be developed in the nearest future.

Optical astronomy, particularly from bases located outside the atmosphere, may thus provide highly valuable information on the existence of planetary systems, and thus on the probable existence of alien civilizations.

D. Ya. M a r t y n o v . The probable candidates for two-way communication can be selected by a fairly certain process of elimination. The hot stars are the first to be eliminated. The evolution of intelligent life on a planet requires very long periods for preparatory processes, e.g., the development of life as such, starting with the most primitive forms. The hot stars, on the other hand, are comparatively young objects. The cold stars, such as class M dwarves, can hardly support intelligent life on their planets, because the energy output is simply insufficient. It is only in the immediate vicinity of a dwarf that the "solar constant" is high enough, but dark satellites of comparatively large mass move only far

from the star (as is obvious from their long orbital periods). Moreover, their orbits are highly eccentric, which is not characteristic of planets.

The probability of finding two civilizations of approximately the same level at one time in one small region of space is of course negligibly small. But if both these civilizations are consciously looking for each other, the chances of an encounter increase to a considerable degree (approximately in proportion to the square root of the probability of coincidence).

A satisfactory theory of the origin of planetary systems would have greatly assisted us in a conscious search for signals. Unfortunately, our achievements in the field of planetary cosmogony are meagre. I. S. Shklovskii has once suggested that planets form due to the rotational instability of the parent star. But planets may also form from a proto-planetary cloud by condensation and coalescence of cold material. The conditions of formation and their dependence on the physical characteristics of the star are entirely different in the two cases.

The technological stage in the development of a civilization may be brief. Human society evolves according to dialectic laws. In particular, each social formation produces antagonistic forces which tend to alter or to break the original order. This struggle of forces, however, need not lead to a catastrophe, and even the modern exponential phase in the development of humanity (characterized by exponential growth of population and energy consumption) may give way to a comparatively calm stage with more rational and economic exploitation of resources, once a classless society has been established.

Humanity has not yet tapped the heat resources of the Earth's interior and the gravitational energy. For example, the energy of a minor earth-quake is greater than the energy released when an H bomb is exploded (10^{26} and 10^{24} erg, respectively). These grandiose resources must and will be harnessed.

All civilizations (the Earth civilization included) apparently tend to advertize their existence. The reasons for this tendency are quite complex. they apparently include scientific curiosity, vanity, and altruism. This considerably simplifies the problem of establishing communication between civilizations.

TRANSMISSION OF INFORMATION
BY EXTRATERRESTRIAL CIVILIZATIONS

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The main and the most promising aspect of the search for signals transmitted by extraterrestrial civilizations is the possibility of gaining an enormous amount of information from these intelligent messages. The most pessimistic estimate in this respect is that there are absolutely no extraterrestrial civilization in the Universe, and the probability of receiving information is zero. This point of view is not inconsistent with the state of things as they are now, but it does seem little probable. In this paper we consider the opposite extreme case, i.e., the most optimistic estimate as regards information reception in the nearest future, which does not contradict observational data either.

Educated estimates concerning the transmission of information over cosmic distances are not beyond our present abilities; one should take account of the known parameters of cosmic objects, the space environment, and optimality criteria of transmission media. These estimates of course cannot be regarded as representative of various particular cases, but some of the arguments and considerations are clearly indisputable.

We shall only deal with the transmission of information by radio waves; there is a sound body of opinion that other transmission channels (individual space flight, launching of space probes, etc.) are much less effective in this respect.

A highly important problem in our context is the level of development of the civilizations from which we expect to receive information. The solution of this problem decides such important parameters as the transmitter power, the quantity of transmitted information, probability of detection, and reliability of signal pickup. We shall show in the following that the problem of the existence of supercivilizations (civilizations converting a power in excess of 10^{33} erg/sec into a coded radio signal) in any part of the Metagalaxy can be solved at present by conducting radio astronomic observations with existing equipment. These civilizations clearly transmit the maximum quantity of information. The search for signals from civilizations approximately at our cultural level requires more sophisticated radio-engineering tools and the probability of establishing contact remains very small.

I. S. Shklovskii has already pointed out in his paper that the exponential technological development of the terrestrial civilization suggests possible intelligent activity on the cosmic scale. This is primarily connected with

the enormous power resources of advanced civilizations. For example, we know that at present the total quantity of energy consumed by humanity is more than $4 \cdot 10^{19}$ erg per second. The annual increment of this figure, according to statistical data for the last 60 years, is $3-4\%$ /1/. The power requirements therefore increase annually by a factor of $1+x$. In t years, the growth factor is $(1+x)^t \approx e^{tx}$ $(x \ll 1)$. Setting $x = 1\%$, we see that in another 3200 years the per-second power requirements will equal the per-second energy output of the Sun, i.e., $4 \cdot 10^{33}$ erg/sec, and in another 5800 years they will rise to the energy output of 10^{11} Sun-like stars. These figures seem improbably large in relation to the present-day state of affairs, but we do not see why future development on the natural and social level should not sustain a similar rate of growth of power requirements.

Proceeding from the foregoing remarks, we suggest the following division of technologically advanced civilizations into three classes:

I — technological level close to the present-day level on the Earth; power requirements $\sim 4 \cdot 10^{19}$ erg/sec.

II — civilizations which have harnessed the energy output of their primary (e.g., a stage in the construction of Dyson's sphere); power requirements $\sim 4 \cdot 10^{33}$ erg/sec.

III — civilizations which have harnessed the energy output of their galaxy; energy requirements $\sim 4 \cdot 10^{44}$ erg/sec.

It takes a few billion years for a type I civilization to develop (the example of our planetary system), while the transition from type I to type II should require no more than a few thousand years and from type II to type III (even if we take into consideration a minimum rate of diffusion of life throughout the galaxy) no more than a few tens of millions of years. Since the age of galaxies is more than 10 billion years, it seems that each galaxy should carry a type II civilization. If this were so, astronomical observations would reveal a considerable number of phenomena which could in no way be attributed to natural causes. Modern astrophysics, however, does not appear to produce direct indications of such phenomena. We thus come to two conclusions: either the probability that a civilization should arise is negligible (so that not every galaxy is inhabited by intelligent beings) or the level of technological development is inherently limited by some hitherto unknown factors. Experimental data do not seem to rule out the possibility that type III civilizations exist in some of the galaxies (though not in every single one) and type II civilizations occupy a few stars in our Galaxy.

At this point we should consider whether the above figures for the power sunk by type II and type III civilizations into radio communication do not amount to outright dissipation. Obviously this is not so. Any system with internal sources of energy should radiate the entire output of its sources, since otherwise the temperature of the system will rise. Radiation of power is thus inevitable, while coding of information virtually consumes no energy. Intelligent communications therefore do not entail an increase in normal power requirements; the only question is the feasibility of building encoding and transmitting equipment. Thermodynamic equilibrium temperature of interstellar radiation, as we know, ranges from a few degrees to a few tens of degrees, which corresponds to the range of millimeter and centimeter wavelengths, i.e., thermodynamically, artificial radiation of power is justified.

Type II and type III civilizations can thus be expected to possess very powerful transmitters. This apparatus can be applied to tackle various problems. First, we may naturally assume that one of the principal problems of intercivilization communications is the transmission of information from a more advanced civilization to a less advanced one, i.e., these high-power transmitters should be probably designed on the principle of optimal learning. Exchange of information between super-civilizations may be realized by means which are inaccessible to us (e.g., extraordinarily beamed antennas).

We now proceed with a more detailed evaluation of communication feasibility on the basis of the above considerations.

1. Transmission channels. It is apparently not disputed that the modern means of communication and television (given a sufficiently powerful transmitter) ensure reliable transmission of any kind of information. The linguistic aspects of this question will be discussed separately, and here it suffices to emphasize the inherent feasibility of the transmission of any information by radio-engineering means.

2. One-way communication. A characteristic feature of our problem is the one-way communication. This is due to the large propagation time of signals in interstellar and intergalactic media (i.e., over distances of up to billions of light years). Under these conditions, with signal propagation time greatly exceeding the characteristic evolutionary time scale of civilizations (e.g., the time for power requirements of a civilization to increase twofold), exchange of questions and answers between civilizations is all but impossible. The transmission should apparently be intended to carry the maximum quantity of information, each side transmitting its entire knowledge at one time.

3. Optimal range for the transmission of information in interstellar space. The main factors which determine the range of radio communication in space are the transparency of the interstellar medium, the amplitude of instrumental and environmental noise, transmitter power, and the size of the antennas. Interstellar dust absorbs electromagnetic radiation at frequencies above 10^{13} c/s propagating in the plane of the Galaxy. For frequencies below 10^8 c/s, the absorption of radio waves in clouds of ionized interstellar hydrogen prevails. The region of high transparency corresponds to minimum space environmental noise. The instrumental noise and the Earth's atmospheric noise can apparently be reduced to a great degree with the aid of low-noise amplifiers and extra-atmospheric antennas; these factors should therefore hardly be regarded as imposing inherent restrictions. The equivalent temperature of intrinsic, unavoidable noise can be written as $T_N = T_n + T_t + T_q$ where T_n and T_t are the temperatures produced by synchrotron and thermal radio background, $T_q = \dfrac{h\nu}{k}$ is the equivalent noise temperature contributed by quantum fluctuations (h and k are Planck's and Boltzmann's constants). Figure 1 plots T_N vs. frequency on the basis of modern radio-astronomic data /2/. Thermal and nonthermal radio emission of the galactic disk will apparently play the main role in establishing long-range communications within the Galaxy. The solid line in Figure 1 corresponds to the radio emission of the galactic disk within the ±50° longitudinal zone from the galactic center. Here

$$T_N \approx 2 \cdot 10^{27} \nu^{-2.9} + 10^{19} \nu^{-2} + 4.8 \cdot 10^{11} \nu. \tag{1}$$

21

In discussing the feasibility of intergalactic communications, we should take account of the background brightness temperature at high galactic latitudes, which is due to the synchrotron radiation from the halo and the Metagalaxy. Here,

$$T_N \approx 10^{26} \nu^{-2.9} + 4.8 \cdot 10^{-11} \nu. \tag{2}$$

In either case, the noise temperature has a pronounced minimum in the $3-10$ cm wavelength region. The frequencies of 10^9-10^{11} c/s are apparently the optimal in this respect.
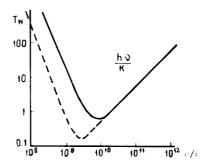
FIGURE 1. Noise spectrum outside the Earth's atmosphere:

solid line — in the direction to the galactic center; dashed line — to the galactic pole.

4. Optimal radiation spectrum of the transmitter.
The upper limit for the rate of information transmission with a transmitter of a given mean power and for a given noise spectrum is found from Shannon's theorem /3/

$$R = \int_{\nu_1}^{\nu_2} \log_2 \frac{s(\nu) + n(\nu)}{n(\nu)} d\nu, \tag{3}$$

where R is the information rate, expressed in binary digits per second, $s(\nu)$ and $n(\nu)$ spectral densities of the transmitted signal and the noise. By solving the corresponding variational problem, we can show that information is transmitted at a maximum rate if

$$s(\nu) + n(\nu) = n(\nu_1) = n(\nu_2). \tag{4}$$

Here ν_1 and ν_2 are the limits of the transmitter passband.

We thus see that the spectrum of an artificial radio source should follow the general trend of the curve in Figure 1, with a reverse sign:

$$s(\nu) = n(\nu_1) - n(\nu),$$

22

i.e., the spectrum of the artificial radio source should be peaked in the 3 − 10 cm region (the red shift is ignored). At lower frequencies, the spectrum should vary as $a - b v^{-2.8}$, while at frequencies above the radiation maximum as $a - c v$ (a, b, c are some constants dependent on transmitter power and passband and on noise distribution). The optimal shape of the transmitter spectrum is thus obtained from considerations of maximum information rate. If this spectrum is sufficiently wide, so that v_2 is much higher than the peak frequency, the high-frequency part of the spectrum carries the greater part of transmission energy and the shape of the spectrum at low frequencies is more or less arbitrary. On the other hand, the linear variation of the spectrum at high frequencies is apparently obligatory.

5. Reliability of signal detection and information reception. One of the common and most effective methods for increasing detection and reception reliability is by raising the receiver signal-noise ratio a. A transmission will be classified as reliable if

$$a k T_N = F_v A_2, \ a > 1, \tag{5}$$

where T_N is the noise temperature reduced to antenna input, F_v radiation flux in a unit fequency interval at the reception site, A_2 the effective surface of the receiving antenna. The flux F_v is defined by

$$F_v = \frac{P G_1}{4 \pi r^2 \Delta v} \cdot \tag{6}$$

where P is the power of the transmitter, $G_1 = \frac{4 \pi A_1}{\lambda^2}$ the gain factor, A_1 the effective surface of the transmitting antenna, r the distance between the receiver and the transmitter, Δv and λ the effective passband and wavelength of the transmitter. The reliability thus depends on the value of the factor

$$a = \frac{P G_1 G_2 \lambda^2}{16 \pi^2 r^2 \Delta v k T_N} = \frac{P A_1 A_2}{\lambda^2 r^2 \Delta v k T_N}, \tag{7}$$

i.e., reliability increases with increasing transmitter power and directivity of transmitting and receiving antennas and with decreasing range and passband of the transmitter. The rate of information transmission is given by

$$R \approx \Delta v \log_2 (1 + a), \tag{8}$$

whence it follows that the increase in reliability by passband contraction involves reduction of the information rate.

6. Isotropic or beamed transmission? An arbitrarily located receiver will detect a transmitter only if its radiation is nearly isotropic, or if the transmitter is coupled into a beamed antenna array which successively radiates in all directions. The latter case obviously represents time-average isotropic radiation, but at any particular instant the signal intensity at the reception site is either 0 or G_1 times the signal amplitude for ideally isotropic radiation. As regards reception, this situation is equivalent to a case of time-variable isotropic radiation with a given mean power. It is known from the theory of information that a maximum number of bits in a given time corresponds to a time-constant

transmitter power (for a given mean power). Any variability or non-uniformity in transmitter power (due to interruption in its operation) reduces the information content of the message.

If the direction to receiver is known, it is clearly desirable to use a beamed antenna array.

Since the signal remains in transit for a very long time, it is little probable that the location of Earth-type civilizations can be known beforehand. We may therefore expect that artificial radio sources radiate isotropically in space and continuously in time, which ensures comparatively reliable detection and maximum information. The above problem should not be confused with the question of call signals — special signals which are not expected to transmit any meaningful information, apart from an indication that the particular radio source is artificial.

7. Information rates for different type civilizations. We give some quantitative estimates.

(a) Let a 10^7 watt transmitter be designed for operation with a maximum range $r = 1000$ light years,

$$A_1 = A_2 = 10^5 \, \text{m}^2, \; T_N = 10° \, \text{K}, \; \alpha = 10^2, \; \lambda = 10 \, \text{cm}.$$

then from (5) we have $F_\nu = 1.4 \cdot 10^{-25} \; \text{W} \cdot \text{m}^{-2} (\text{c/s})^{-1}$, from (7) $\Delta \nu \sim 7 \, \text{c/s}$, and from (8) $R \sim 50$ bits/sec.

(b) Let a transmitter with a power of $P \sim 10^{24}$ erg/sec (of the order of solar radiation reaching the Earth) be designed for transmission over a maximum range $r = 1000$ light years; the other parameters as in (a). Then $\Delta \nu \sim 7 \cdot 10^{10} \, \text{c/s}$, $R \sim 5 \cdot 10^{11}$ bits/sec. For an isotropically radiating transmitting antenna ($G_1 = 1$), we have $\Delta \nu = 600 \, \text{c/s}$, $R \sim 4 \cdot 10^3$ bits/sec.

We thus see that even civilizations which are close to our level (type I) can transmit messages with a fairly high information rate. The results obtained for type II and type III civilizations are even more promising.

Assuming isotropic radiation, $A_2 = 10^5 \, \text{m}^2$, noise temperature $T_N \sim 1 °\text{K}$, and $\alpha = 10^2$, we find from (5) that $F_\nu = 1.4 \cdot 10^{-26} \; \text{W} \cdot \text{m}^{-2} (\text{c/s})^{-1}$, a quantity which is reliably recorded by existing radio telescopes. (The detection of this radiation of course requires comparatively simple equipment; unlike the reception of information, detection can be achieved by conventional radio-astronomic smoothing and averaging techniques and, given a sufficiently broad signal band, the radiometric gain $\sqrt{\Delta \nu \tau}$, where τ is the integration time, may raise the sensitivity by $3 - 4$ orders of magnitude.)

Let us now evaluate the rates of information transmission by super-civilizations. Reception reliability is ensured by putting $\alpha = 10^2$, and the information rate $\sim \Delta \nu$ is $1/7$ the rate from (8). For type III civilizations, we should take account of the variation of I_λ with frequency according to relation (1). For type II civilizations, we take $T_N = 1 °\text{K}$. Table 1 lists estimates for three different distances, corresponding to information transmission within the Local Group and within the bounds of the observed part of the Metagalaxy. An isotropic transmitter is assumed throughout.

The above estimates show that signals and information transmitted by type II and type III civilizations virtually anywhere in the Universe can indeed be detected and reliably received. Transmitter spectra of type III civilizations anywhere in the Universe and of type II civilizations in our Galaxy are of width comparable with the spectra of natural radio sources, and in the following we shall therefore discuss the criteria for differentiating artificial from natural sources.

Type I civilizations (for communication at any range) and type II civilizations (for intergalactic communication) may use only monochromatic signals ($\Delta\nu\ll\nu$), whose detection constitutes technically a formidable task. In planning a search for signals of artificial origin, these two essentially different points must be taken into consideration. The detection of wideband signals is much simpler. Moreover, it can be expected that if type II and type III civilizations actually exist, then any type I civilization which has detected their signals will start beamed transmission in the direction of the higher civilizations and, in principle, it will remain undetectable to us. Radio signals from supercivilizations therefore suggest themselves as the first natural step in this search for artificial radio sources.

TABLE I

Number of bits per sec $\sim \Delta\nu$

Civilization type	Transmitter power	10^5 light years	10^7 light years	10^{10} light years
II	$4\cdot10^{33}$erg/sec	$3\cdot10^9$	$3\cdot10^5$	0.3
III	$4\cdot10^{44}$erg/sec	$2.4\cdot10^{15}$	$2.4\cdot10^{13}$	$3\cdot10^{10}$

To illustrate the possibilities of information transmission by type II and type III civilizations, let us estimate the time of transmission of all the manuscripts and printed publications existing to date on the Earth ($\sim 10^8$) through a 10^9 c/s channel. Assuming that each opus contains on the average some 10^6 binary digits, we find that the total quantity of 10^{14} bits can be transmitted in 10^5 sec, i.e., in a single day. However, a comprehensive picture of the scientific, technical, and cultural development of the Earth can be sent without actually transmitting all the 100 million volumes: this information possesses enormous "redundancy". All the fundamental data can be apparently summarized in a 100 thousand volumes of 10^6 bits each, which gives a total of 10^{11} bits and a transmission time of 100 sec through the same channel. Of course it should be expected that the cumulative knowledge of type II and type III civilizations is many orders of magnitude higher than the entire information at our disposal now.

8. Call signals and artificiality criteria. As we have already observed, the radiation from an artificial radio source should possess a variety of characteristics which facilitate its detection, identification of artificiality, and eventual decoding. We now list the various characteristics of this kind.

(a) Artificial radio sources should have very small angular dimensions. Indeed, source intensity can be changed with a period of $1/\Delta\nu$ only if its apparent size $\varphi < c/r\Delta\nu$ (otherwise, delay of signals radiated by different parts of the source will involve some loss of information).

It is easily seen that for all the examples that we have considered above, the angular size should be less than 0".001. The only exception is apparently provided by type III civilizations: their radiation can be visualized as being made up of a great number of transmitters which are distributed in a certain way over the spectrum and throughout the galaxy. If the receiver band covers more than a single source, the apparent angular size is

clearly the angular size of the entire system. Given a narrow-band receiver, which picks up the signal from a single transmitter only, we return to a situation where the criterion of point-like angular size is again in force. The great majority of natural radio sources in the Universe have an apparent angular size of over 0".1. The point-source criterion therefore immediately focuses our attention on very few radio sources which deserve further study.

(b) Time variability which is not accounted for by statistical fluctuations. "Suspects" are expected to emit special signals which provide direct indication of their artificiality: this can be done by periodic "shut down" of the source or, conversely, periodic radiation of high-intensity pulses. However, in looking for this kind of call signals we should bear in mind that considerations of maximum information rate restrict the transmission of call signals to the very first instant of source identification: they cannot be sent too often (as, incidentally, is the case in regular radio communication). Some statistical characteristics of the signal should also be investigated. In particular, to ensure reliable reception and decoding, a meaningful signal should possess a much lower enthropy than Gaussian noise. It is advisable to concentrate on the modulation frequency spectrum of the suspected source: this may characteristically reveal some monochromatic bands (e.g., scanning frequency, frame frequency in television transmission). The coherence of radiation at nearby frequencies should be examined, in order to determine the channel width of the transmitter.

(c) The analysis of the signal spectrum is another important point. As we have already seen, considerations of maximum information rate require a spectrum with a linear high-frequency branch. Moreover, some features of a wide band spectrum may act as call signals: this peculiarity should be particularly expected near the 21-cm line. Interstellar transmission of information at this frequency is inexpedient, since the signal is readily absorbed by neutral hydrogen. It is therefore not unreasonable to suggest that a $1-2$ Mc/s band of, say, square-pulse form should be specially incorporated into the continuous spectrum of the artificial source to be used as an indication of artificiality.

If the transmitter power is inadequate for broad-band transmission, the detection of a monochromatic point source is in itself a reasonable proof of source artificiality.

What can we now say on the possibility of detection of artificial radio sources in the light of the above considerations and the available radio astronomical data? Unfortunately, not a single radio survey of the sky has been attempted at centimeter wavelengths. Radio surveys have been made at longer wavelengths, i.e., outside the optimal frequency region, and they have hardly any bearing on our problem. Among the sources listed in these surveys, some twenty or thirty have apparent angular sizes of 1"−10" /4/. Some of the sources have been identified with peculiar optical objects. Most of the sources, however, remain unidentified.

As an example, we can mention two sources, CTA 21 and CTA 102, discovered at the California Institute of Technology /5/. Their angular dimensions are less than 20" and, which is particularly interesting, their spectra are very close to the expected artificial spectrum. Figure 2 plots the theoretical expected spectrum and the observational data /6/ for the two sources. For purposes of comparison, this figure also gives the

spectrum of a typical natural radio source Virgo A (the ordinate axis
scale for this source has been contracted by a factor of 10). Although
in radio astronomy the spectra are conventionally represented in logarithmic
coordinates, our curves are plotted in linear scale: to ensure optimum
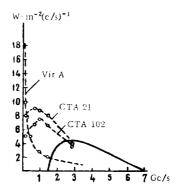information rates the spectrum should be linear in linear coordinates.

FIGURE 2. Solid curve — expected spectrum
of radio signals transmitted by a supercivili-
zation; dashed curves — spectra of CTA 21
and CTA 102 radio sources, which are
suspected of being artificial, and the spec-
trum of the radio galaxy Virgo A.

The radio source LHE 210, LHE 459, and LHE 523 apparently fall under
a similar category: their spectra at decimeter wavelengths were plotted
from observations made at the Shternberg Astronomical Institute at 32 cm /7/.

We should also mention some high-resolution radio observations of the
Andromeda Nebula /8/. According to these observations, several sources
of small angular size were discovered in the nebula in the decimeter region.
The observations of Lynds /9/ at 10 cm, however, did not detect any
radiation with a flux exceeding $5 \cdot 10^{-27}$ W $\cdot$ m^{-2}(c/s)$^{-1}$ from the nebula.
No other relevant data are apparently available today.

An acute need is thus felt in radio surveys of the sky at 3 — 10 cm
wavelengths. When this survey is carried out, it is advisable to apply
the point-source criterion immediately, thus reducing the number of
sources to be inspected by many orders of magnitude. For example, if
the observations in the centimeter region are made with an interferometer
with an 0''.1 lobe width and a flux sensitivity of 10^{-27} W $\cdot$ m^{-2}(c/s)$^{-1}$, it
seems (on the basis of previous observations at meter wavelengths) that
the number of natural sources of so small angular size will not be greater
than 10 — 20. If the resolution is further improved, each of the sifted
objects will prove to be unique.

The most favorable region of the sky for the search for artificial signals
is apparently in the direction to the galactic center, since the line-of-sight
density of the stellar population here is the highest. The nearest galaxies —
the Magellanic Clouds and the Andromeda Nebula — should also be
surveyed as soon as possible.

In parallel with the centimeter wave survey, it is advisable to launch a detailed analysis of previously discovered suspect sources in the light of the artificiality criteria discussed above.

In conclusion we should like to observe that our estimates are of highly tentative nature. They nevertheless seem to indicate that the Earth civilization is not a unique phenomenon in the Universe and that modern radio physics is up to the task of establishing radio contact with other civilizations. It is very difficult to imagine that of the 10^{11} stars in our Galaxy, the Sun is the only one privileged with sustaining a civilization. It is even less credible that this is the only case out of 10^{10} galaxies in the observed part of the Universe. Anyhow, the final proof will be supplied by the experiment. The program outlined in this paper appears to be reasonable and feasible, particularly as a first stage in this work. Radio astronomic surveys will apparently play a decisive role in the development of this problem.

<div align="center">QUESTIONS</div>

E.G.Mirzabekyan. If I understand you correctly, the main criterion of artificiality is the source spectrum, then its angular size, etc. Should we examine other criteria if, say, the spectrum meets the artificiality criterion?

Answer. The criterion of angular size is apparently the most important of all: it immediately reduces the number of objects to be considered by 2 or 3 orders of magnitude, and even more, if we specify that only radio sources measuring less than $0''.1$ (with a detection threshold of 10^{-27} W·m^{-2}(c/s)$^{-1}$) should be approached. The other criteria apparently further limit the number of sources to be examined.

V.A.Ambartsumyan. I want to call your attention to the most paradoxical part of your paper. I reserve my comments for the time being, and I only want to verify that I have correctly understood the point you have tried to make: in your opinion it is best to send a monochromatic, anisotropic, intermittent signal, and then you come to the conclusion that we should look for a continuous, isotropic, and uninterrupted signal. Is that so?

Answer. Quite right. The considerations of maximum information rate for a given transmitter power always impose definite optimality requirements on band width, anisotropy, and radiation time. For type II and type III civilizations, these standards can be met even though they transmit isotropically and continuously, in a broad frequency band.

G.M.Aivazyan. What are the distances of the sources that you have mentioned as an example of probable artificial objects?

Answer. These sources have not been identified with optical objects and their distances are therefore unknown. Yu.N.Pariiskii will report some results of an attempt to identify these sources.

P.M.Geruni. Why in your opinion the survey of the entire sky should be completed in one day?

Answer. To increase the information rate.

Bibliography

1. Putnam, P.C. Energy in the Future. —New York. 1948.

2. Oliver, B.M. — International Science and Technology, No. 10 : 55. 1962; Turtle, A.J., J.F.Pugh, S.Kenderdine, and I.I.K.Paulini-Toth. — Month. Not. Roy. Astron. Soc., 124 : 297. 1962; Wilson, R.W. — Observations of the Owens Valley Radio Observ., Cal. Techn., No. 3. 1963; Altenhoff, W., P.G.Mezger, H.Strassl, H.Wendekerr, and G.Westerhout. — Veröff. Univ. - Sternwarte zu Bonn, No. 9. 1960.

3. Goldman, S. Information Theory. — N.Y., Prentice Hall. 1953. [Russian translation. 1957, p. 186.]

4. Allen, L.R., B.Anderson, R.G.Conway, H.P.Palmer, V.C.Reddish, and B.Rowson. — Month. Not. Roy. Astron. Soc., 124 : 477. 1962.

5. Harris, D.E., and J.A.Roberts. — Publ. of the Astron. Soc. of Pacific, 72 : 237. 1960.

6. Conway, R.G., K.I.Kellerman, and R.I.Long. — Month. Not. Roy. Astron. Soc., 125 : 261. 1963.

7. Sholomitskii, G.B., V.N.Kuril'chik, L.I.Matveenko, and G.S.Khromov. — Astronomicheskii Tsirkulyar, No. 283. 1961; Astronomicheskii Zhurnal, in print. 1964.

8. Kraus, J. — Nature, 198 : 844. 1963; Sky and Tel., 26(1) : 12. 1963.

9. Lynds, C. — Publ. Nat. Radio. Astron. Observ., 1(7) : 112. 1961.

OBSERVATIONS OF THE PECULIAR RADIO SOURCES
CTA 21 AND CTA 102 AT PULKOVO

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In the previous paper (see also /1/) a suggestion was made that the radio sources CTA 21 and CTA 102, whose spectrum is peaked at decimeter wavelengths, are of artificial origin. The main arguments in support of this opinion are the following:

1. The good fit of the observed spectrum to the expected curve /1/.
2. Small angular size of the sources.

To satisfy N. S. Kardashev's inquiries, we measured the integral flux of these two radio sources in the centimeter wavelength region using the Pulkovo large radio telescope and a wide-band parametric amplifier at 6.4 cm. The angular diameters of these sources and their right ascensions were also measured. The smoothed drift curves of the radio sources are reproduced in Figures 1a and 1b. The results of measurements are summarized in Table 1. The declinations are borrowed from /2/.

TABLE 1

CTA 21 $P = 2.7 \pm 0.3 \cdot 10^{-26}$ W·m^{-2}(c/s)$^{-1}$; $\alpha_{1950} = 3^h 16^m 08^s.63 \pm 0^s.3$, $\varphi_i \leqslant 1'$,

$\delta_{1950} = 16° 17' 45'' \pm 8''$.

CTA 102 $P = 3 \pm 0.3 \cdot 10^{-26}$ W·m^{-2}(c/s)$^{-1}$; $\alpha_{1950} = 22^h 30^m 07^s.94 \pm 0^s.3$, $\varphi_i \leqslant 0'.2$,

$\delta_{1950} = 11° 28' 49'' \pm 8''$.

The last column of the table gives the estimated angular diameters of these sources; apart from measurement errors, CTA 102 is a point source, while CTA 21 is probably extended. To corroborate the latter point, another series of observations was made, and again a substantial broadening of the antenna pattern was observed for CTA 21. The source diameter between points of zero power is less than 1', and if the broadening is indeed significant, we have here a double source. Unfortunately, the accuracy of our measurements does not enable us to reach a firm conclusion in this respect. The two fluxes correspond to two extreme values of the angular diameter of CTA 21: $3 \cdot 10^{-26}$ W·m^{-2}(c/s)$^{-1}$ for $\varphi_i \simeq 1'$ and $2.4 \cdot 10^{-26}$ W·m^{-2}(c/s)$^{-1}$ for $\varphi_i < 0'.2$.
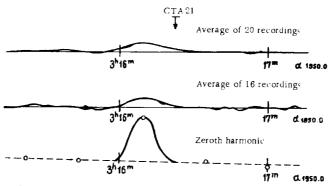
FIGURE 1a. Drift curve of CTA 21. Bottom — integral radio power at 4' intervals near the radio source (the "zeroth harmonic", which specifies the integral radio flux).
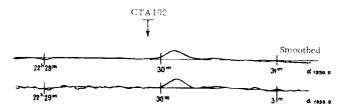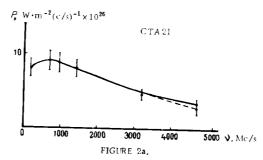

FIGURE 1b. Drift curve of CTA 102 (bottom). Top — the smoothed curve at 1' intervals.
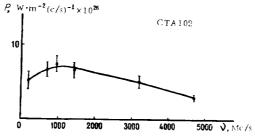

FIGURE 2a.

FIGURE 2b.

31

The integral spectrum of these radio sources is plotted in Figures 2a and 2b in logarithmic and linear scale. The high frequency points follow fairly closely a linear flux vs. wavelength dependence. This is the expected dependence for artificial radio spectra on account of the linear variation of the quantum fluctuation power with frequency (per unit frequency interval; for more details, see /1/).

This spectrum, however, is characteristic of other objects as well (e.g., the "quasar" 3C 286), and it can be explained within the framework of the synchrotron radiation mechanism. For example, Figures 3a and 3b plot the radiation of a monoenergetic ensemble of ultrarelativistic electrons in a random magnetic field (the solid curves; the figure is borrowed from /3/). The agreement between the observed and the calculated spectra is astonishing, especially for CTA 102. We are therefore inclined to accept Kellerman's interpretation /3/. Note that the primary electron spectrum need not be monoenergetic. It has been shown /4/
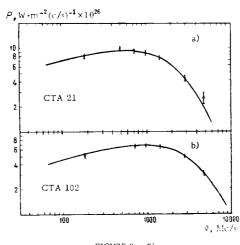
FIGURE 3a, 3b.

that any power-function spectrum is converted to a monoenergetic spectrum by the simultaneous interaction of Fermi statistics (or the betatron mechanism) and deexcitation in the magnetic field under steady-state conditions. However, it follows from the calculations of /5/ that no secondary electrons form in these objects, since the spectrum of secondary electrons is fairly broad even if the proton spectrum is monoenergetic.

Making use of our right ascensions for these sources and of the declinations from /2/, we tried to establish the optical identity of the radio sources CTA 21 and CTA 102. The photographs in Figures 4a and 4b show optical objects which are closest to the position of the radio sources.

A detailed inspection of the Mount Palomar Atlas photographs for the region of the sky near CTA 21 has shown that the optical object located 12" to the east from the radio source (marked with arrow) is a very weak stellar object of $21^m - 22^m$. Its color is red: in blue light (see Figure 4c) it is virtually invisible. The nearest object to the west is blue. We should therefore also consider the possible identification of the radio source with this blue object.

32

FIGURE 4a. The region of the sky near CTA 21, red light (E plate). Scale, 1mm to 0'.87.

FIGURE 4b. The region of the sky near CTA 102, red light (E plate).

FIGURE 4c. The region of the sky near CTA 21, blue light (O plate).

A stellar object of 19^m-20^m is located very close to CTA 102. Some 6^s to the east and $30''$ to the north from the radio source, there is a double galaxy of $\sim 18^m$, whose northern component is brighter than the southern one; position angle of the axis of the two components $\sim 0°$, component separation $5''$. This galaxy, however, is clearly beyond the margin of error of measurements in right ascension. The object which coincides with the radio source is of bluish color.

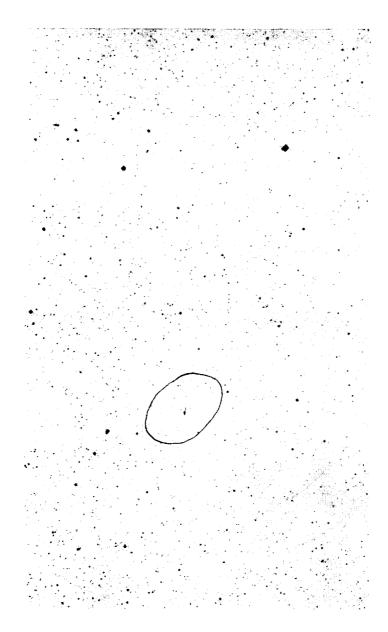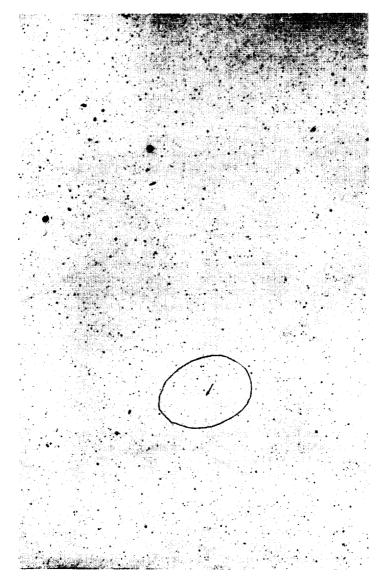We thus come to the conclusion that both sources are related to extremely faint stellar objects. It is significant that a more accurate determination of the source coordinates in future will only strengthen this conclusion, since nearby objects, if any, are all fainter than 22^m-23^m.

In /1/, the energy of the optical radiation of a star (or a system of stars) is assumed as a reasonable upper limit for the power available to type II and type III civilizations. It is easily seen that for CTA 21 and CTA 102 the emitted radio power is greater than the power of optical radiation. Indeed, the integral flux of radio waves for CTA 21 and CTA 102 is nearly $6 \cdot 10^{-13}$ erg/sec·cm². Assuming a nearly solar spectral composition of the optical radiation, we obtain a luminous flux of $\sim 1.4 \cdot 10^{-13}$ erg/sec·cm² at the Earth's surface for a stellar object of 21^m, i.e., one quarter of the radio flux. This relation is observed irrespective of the actual absolute luminosity of the object. The transmitter power can hardly be more than a few percent of the total energy resources of type II or type III civilizations. The observed radio power is therefore higher by two orders of magnitude than the upper limit set for an isotropic artificial source.

If we assume beamed radiation, the energy difficulties can be overcome by taking transmitter directivity G higher than 100. Seeing that $G = 4\pi A/\lambda^2$, where A is the effective surface efficiency of the transmitting array, $\lambda \sim 0.3$ m, we find $A > 1$ m², reflector diameter D over 1 m, $\lambda/D < 20°$. It is fairly obvious, however, that $A \gg 1$ m², since the enormous power ($10^{33} - 10^{44}$ erg/sec) required for this transmission cannot be concentrated in so small a volume. The directional gain of the system should therefore be much higher, also. If the antenna system is rotated in space, we should see brief radio flashes at the instant of our entering the transmitter angle of view. During the last 3 years, however, nobody has observed any variations in radio power received from CTA 21 and CTA 102. The only conclusion in the light of these findings is that our planetary system is being continuously "illuminated" by an alien type II or type III civilization, at least for the last three years.

We thus see that the spectral peculiarity of CTA 21 and CTA 102 is not a decisive criterion of their artificiality. Peculiarity of angular size (pointlike sources) is possibly a more reliable criterion. We would like to emphasize, however, that all these artificiality tests are relative to a certain degree. It is easy to foresee that as the sensitivity of radio telescopes increases, a greater number of small-sized "natural" objects will become accessible to observation: stars, planetary nebulae, supernovae in nearby galaxies, etc. A new criterion will thus be required for identifying the "suspects". Various manipulations of the radio spectrum could possibly provide the necessary information. But here again "natural" manipulations can be expected, both in amplitude (slowly varying radio component of stars, radio bursts, cepheids, etc.) and in frequency (dynamic bursts, possibly cepheids, etc.). In our opinion, the only absolute artificiality criterion is actual decoding and application of the received information.

V. A. Ambartsumyan. You have found $z_{rad}= 300\,z_{opt}$. If we take $z_{opt}=z_{rad}$, the absolute magnitude will correspondingly drop to the absolute magnitude of the source in Cygnus. Does it mean that the radio flux from CTA 21 is equal to the flux from Cygnus A?

Answer. If we assume that the difference in the ratio of absolute radio and optical luminosities is compensated by the difference in the stellar magnitudes of Cygnus A and CTA 21, then the flux density (integrated over all the frequencies) as seen on the Earth will indeed be the same for the two objects.

I. D. Novikov. You have mentioned that the first of the two radio sources is possibly a double source or, if not so, then at least its angular diameter is somewhat greater than the width of the antenna pattern. Is it not a tentative proof of the natural origin of this and other similar sources?

Answer. In my opinion, this is a conclusive proof (if the existence of "families" of type II and type III civilizations is ruled out as quite improbable).

E. Ya. Boguslavskii. What were the specifications of the parametric amplifier used in your measurements?

Answer. Passband 200 Mc/s, noise temperature (including channel noise, antenna noise, etc.) 400 °K, sensitivity 0.05 °K for a time constant of 3 sec.

Bibliography

1. Kardashev, N. S. — Astronomicheskii Zhurnal, 41 · 282. 1964.

2. Read, R. B. — Ap. J., 138 (1) : 1. 1963.

3. Kellermann, K.— Owens Valley Radio Observatory, No. 3. 1964.

4. Kaplan, S. A. and S. B. Pikel'ner. Mezhzvezdnaya sreda (Interstellar Space). — Moskva, Fizmatgiz. 1963.

5. Ginzburg, V. L. and S. I. Syrovatskii. Proiskhozhdenie kosmicheskikh luchei (The Origin of Cosmic Rays). — Moskva, Izdatel'stvo AN SSSR. 1963.

RADIO-ASTRONOMIC ARTIFICIALITY CRITERIA
OF RADIO SOURCES

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N. S. Kardashev in his paper expressed the opinion that radio transmitters of extraterrestrial civilizations sending broad-band isotropic transmissions are externally similar to ordinary discrete radio sources associated with galactic and extragalactic nebulae. Since the number of discrete radio sources has already climbed into the thousands, the search for artificial radio sources is a formidable task. N. S. Kardashev therefore proposed several astronomical criteria of probable artificiality of radio sources, which are based on a detailed analysis of the properties of natural sources and general considerations concerning the feasibility of interstellar communications. Kardashev's three artificiality criteria are the following:

1) spectrum peaked in the 3 — 10 cm range, falling off linearly in the high-frequency region;

2) source of small angular size;

3) signal variable in time.

Let us consider each of the criteria in some detail.

1. Spectrum. Natural sources mostly possess a so-called power-function spectrum, the radio power falling off with frequency as $f^{-\alpha}$. In some cases, the spectral index $-\alpha$ changes abruptly (from one negative value to another), causing a so-called break in the spectrum. The spectra of some radio sources are characterized by a positive index at low frequencies. In this case, the source spectrum is peaked at meter, and occasionally decimeter, wavelengths. In principle, of course, there may also exist radio sources with a maximum in the centimeter region; the spectra of these sources are close to the expected artificial spectrum. The linearity of the spectrum in the high-frequency region is a stronger criterion of artificiality. Linear behavior is indicatory of a finite frequency band, i. e., a limiting transmission frequency exists. Natural sources do not have a limiting frequency: here the frequency axis is the asymptote of the spectrum. For example, the spectrum of the Crab Nebula extends from the radio region to the infrared and farther on into visible light. To determine whether the spectrum is a linear or a power function, high-precision flux measurements should be made in a broad frequency range. In principle, the nature of the spectrum can be derived from fairly accurate measurements of the radio flux at three frequencies.

2. Angular size. According to the current notions, all radio sources occupy a finite area of the celestial sphere. All the known radiation mechanisms cannot provide infinitely large fluxes per square

second of arc due to self-absorption. Therefore, even synchrotron radiation — a highly efficient mechanism — is restricted by certain minimum size requirements for a given radio flux. For comparatively weak radio sources with fluxes of the order of 10^{-25} W $\cdot$m^{-2}(c/s)$^{-1}$, the minimum angular size is 0".005 at 50 cm and 0".0003 at 5 cm. At present the angular diameters of radio sources are measured with maximum resolution of nearly 1", and these measurements indicate that the great majority of radio sources are much larger than 1". The expected number of radio sources with angular diameters less than 0".001 is theoretically estimated at 50.

On the other hand, the angular size of artificial radio sources whose transmitter power is of the same order of magnitude as the energy output of a star should be exceedingly small for the following two reasons. First, the sphere of activity of civilizations of this kind is limited by the size of planetary systems, and already at distances of 10 ps, the apparent angular size of a planetary system is less than 1". Second, the apparent angular size of artificial transmitters is limited by the rate of information transmission. Indeed, if the information is transmitted at a rate of n bits/sec, the apparent angular size of the transmitter should be less than c/nR, where R is the distance to transmitter. Transmission rates of $n = 10^6$ bits/sec correspond to a linear size of 300 m. This does not mean that the physical size of the transmitting system must be less than 300 m. It is apparently impossible to generate high power (of the order of 10^{33} erg/sec) in so small a volume, and indeed this is quite unnecessary. The above estimates refer to an equivalent incoherent radiator, since it is only to this kind of sources that the concept of angular size applies. Coherent transmission makes it possible to employ physically larger radiators without increasing the apparent angular size. A transmitter based on this principle can be visualized, for example, as a spherical traveling-wave amplifier with a radius of a few astronomical units (Dyson's sphere), with a master oscillator of comparatively low power output at its center. This system ensures a nearly isotropic transmission of very high power and speed (high information rates). The apparent angular size of the system is the size of the oscillator, since the spherical TW amplifier does not distort the wave front as radiated by the master oscillator. The table below lists the limiting angular dimensions for various rates of transmission at a distance of 1 kps.

n, bits/sec	$3 \cdot 10^{-8}$	10^{-5}	$3 \cdot 10^{-4}$	1	10^3	10^6	10^9
θ''	70	0.2	0.007	$2 \cdot 10^{-6}$	$2 \cdot 10^{-9}$	$2 \cdot 10^{-12}$	$2 \cdot 10^{-15}$

Note: $n = 3 \cdot 10^{-8}$ corresponds to a transmission of 1 bit per 1 year.

$n = 4 \cdot 10^{-5}$ corresponds to a transmission of 1 bit per 1 day.

$n = 3 \cdot 10^{-4}$ corresponds to a transmission of 1 bit per 1 hour.

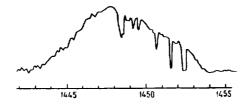We see from the table that the angular size of high-speed transmission systems is virtually inaccessible to measurements (the maximum resolving power of modern radio interferometers is 1"). The minimum angular diameter of these systems, as well as the rate of transmission, are apparently limited by the dispersion of phase velocity in interstellar and interplanetary inhomogeneities. In this case, however, information can

be transmitted in a very broad band by using multichannel systems; the above considerations then apply to each individual channel.

3. Variability. It is understood that the power of the signals transmitted by extraterrestrial civilizations should somehow vary in time (with a characteristic time of over 1 sec). In low-rate transmissions, this variability corresponds to signal modulation introduced by the encoding of information. In high-rate transmissions, this variability may correspond to the beginning or the end of a certain transmission session, or else play the role of "call signals" which are intentionally incorporated in the message to facilitate identification of signals of artificial origin. The main difficulty is that the characteristic time of signal power variability is not known. Is it seconds or minutes, or is it years? Fortunately, all the known natural radio sources emit at a remarkably constant rate in the radio range. This has been established by theoretical calculations and by direct measurements. Only some sources identified with highly non-stationary objects reveal slow variation of the radio flux. For example, the radio flux of Cassiopeia A, associated with the expanding shell of a previous supernova, monotonically decreases at a rate of nearly 2% per year. A discovery of rapid (and, if possible, regular) variations of radio flux thus would cast a serious suspicion of artificiality.

RADIO EMISSION OF STARS

The rapid advance of radio astronomic techniques recently led to the detection of radio waves emitted by some nonstationary stars, in particular, UV Ceti variables. The radio emission here is in the nature of bursts some 10 min long, which are approximately synchronous with the luminosity flashes in the visible spectrum. Sometimes, the smooth variation of the radio flux is combined with abrupt fluctuations (see figure) of a few second's length. These radio waves, at a first glance, may satisfy all the three artificiality criteria: the spectrum, although not known with any degree of accuracy, may turn to be close to the expected artificial spectrum; the

A recording of the radio emission of V 371 Orionis at 410 Mc/s.

angular size, though not measured, may prove to be less than 1/1000 of a second of arc; the fadeouts appearing in the form of deep depressions in the figure are reminiscent of "call signals" (in fact, these minima are probably attributable to the radiometer time constant). These radio waves, however, are not artificial. Similar radio bursts are observed in a great

variety on our primary, the Sun, though on a smaller scale; the phenomenon is apparently due to nonstationary processes in stellar atmospheres. Interference from variable radio emission of nonstationary stars should be taken into consideration in a search for artificial signals. Anyhow, the discovery of new radio stars will be quite a useful byproduct of this search.

It should be emphasized that the above radio-astronomical criteria are adapted to the present-day level of radio-astronomical development. Radio surveys can thus begin to-day, with the existing radio telescopes, whose signal-noise ratio is $1/10-1/1000$ for most sources. Reception and decoding of information of course requires a signal-noise ratio greater than 1, i.e., antennas of higher surface efficiencies and receivers of higher sensitivity than those available to-day should be built.

STATISTICAL PROPERTIES OF SIGNALS

It is well known that, to ensure optimal utilization of the communication channel, the statistical properties of the signal should be close to the statistical properties of random noise. Hence, an efficiently coded signal is virtually indistinguishable from noise. In this case, decoding is practically impossible, unless the code is known beforehand. Therefore, we must not expect the extraterrestrial civilizations to follow the course of maximum information content, which requires perfect coding of the signal. Redundancy, i.e., imperfect utilization of the communication channel capacity due to statistical correlation of the signal components, is an inherently necessary condition for code breaking. In this context, redundancy should be interpreted as quite general statistical properties — from simple repetition of code combinations to a language study course (e.g., the LINCOS language). Redundancy is also a characteristic property of some modulation techniques, e.g., amplitude modulation. Artificial signals thus should possess a fairly high redundancy. As regards natural radio sources, their radio emission is a pure uncorrelated random noise, the combined outcome of a multitude of charged particle emissions. It is easily seen that the integrated emission is normalized in virtue of the limit theorem of the probability theory.

The search for artificial radio sources should therefore include a comprehensive analysis of the statistical properties of the signal which distinguish it from the background noise of natural radio sources. Among these characteristics we have the moments of the distribution function

$$M_n = \int x^n p(x)\, dx,$$

the autocorrelation function

$$\varphi(\tau) = \int x(t)\, x(t-\tau)\, dt,$$

the spectrum correlation function

$$\psi\left(\Delta f\right) = \int x\left(f\right)x\left(f - \Delta f\right)df,$$

etc.

CONCLUSION

Although each of the artificiality criteria discussed in this paper is not single-valued, it is our opinion that the combined application of all tests should be sufficient for the detection of artificial radio transmitters. Anyhow, even the discovery of natural radio sources meeting all these criteria will be a highly significant radio-astronomic event worth the effort.

As we have previously observed, the search for artificial radio sources can begin even to-day, with the modern tools of radio astronomy. It seems to us that the first step in this direction is a survey of the sky with an interferometer having a resolution of the order of 0".1. This survey will eliminate nearly all the natural radio sources. The remaining sources should then be measured with instruments of higher resolving power to establish their size, spectral composition, and degree of constancy of the radio flux. The next stage is the analysis of the statistical properties of the signal. If this sequence of sifting operations leaves a certain number of "suspects", superlarge antennas should be erected for reception and decoding of information.

RECEPTION OF SIGNALS TRANSMITTED BY
EXTRATERRESTRIAL CIVILIZATIONS

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The development of radio physics, cybernetics, and some other related scientific disciplines enables us to consider the problem of reception of signals from extraterrestrial civilizations (EC) in a more practical, objective light. This problem obviously comprises two parts: detection of the signal and decoding of the received information. In our opinion, one of the main difficulties in EC signal detection is the precise definition of what actually constitutes an EC signal among the background emissions of natural sources. In this connection, we should remember that natural radio sources may actually emit "signals" of fairly complex modulation.

N. S. Kardashev /1/ discussed several criteria of EC signals: (1) point-like source, (2) frequency range coinciding with the region of minimum natural noise, (3) shape of spectrum suitable for transmission at a maximum information rate. Golay, in a previously published communication /2/, proposed other criteria: (4) statistical amplitude properties identical to those of signals emitted by an autogenerator — a feedback-controlled oscillator (as distinct from the statistical properties of the noise envelope passing through a selective filter), (5) coherence of the signal. Tests (1) —(5) are not of equal physical importance and they do not ensure absolutely reliable identification of an EC signal, even if it is sufficiently powerful for detection with the available equipment. Since the sensitivity of radio-astronomic instruments will keep on increasing in the near future, a fast growth in the number of "suspects" can be expected. The fundamental task of EC signal identification should therefore be left to automatic equipment. In this connection, the intuitive criterion of signal "strangeness" requires a more exact definition. We do not propose any new criteria here: our paper is limited to a discussion of the existing tests.

It should be emphasized that an information-saturated signal is in no way distinguishable from random noise. It is therefore only reasonable to expect that this "meaningful" signal will be accompanied by a special attention-catching device, the so-called EC "call signals". Our efforts should therefore be focused on the distinctive features of these "call signals". The statistical criteria presented in /2/ are based on the assumption that natural sources are not self-oscillatory systems with feedback control. This proposition, if taken literally, is incorrect, since not only cepheids, but even such a typical star as our Sun (with its cyclic activity) is a natural astrophysical feedback oscillator. However, all the known natural sources

of this kind constitute a specific group: the natural oscillations of the object do not affect the emission frequency; they modulate the carrier. Only future observations will decide whether there are any sufficiently powerful quasi-monochromatic natural radio sources whose natural oscillations are not restricted to a modulation envelope, but actually introduce independent high-frequency radiation. Theoretically, we can propose a model of a nonequilibrium ("maser") medium where the amplification conditions are such a function of the intensity of the amplified radiation that absorption gives way to amplification only when a certain intensity level has been reached. In the case of generation in "free" space (i.e., without solid reflectors), a signal is obtained whose amplitude distribution is closer to the feedback oscillator signal than to random noise transmitted through a linear selective system. Ignoring Golay's erroneous statement on the alleged difference between the concepts of a coherent and a quasimonochromatic signal, we readily accept his opinion that such signals are ideally suited for the part of call signals.

The choice of the exact shape of call signals is connected with the necessity to compensate the distortions of the "meaningful" signal. Consider the following example. Dispersion produced by the scattering of radio waves by free electrons of the interstellar medium introduces the following delay in the limiting signal harmonics*:

$$\Delta t \sim \frac{10^8 NR}{cf^3} \, \Delta f.$$

where N is the electron concentration, R the distance, f the frequency, Δf the frequency band, c the velocity of light. Already at distances comparable with the size of our Galaxy, the delay Δt is substantial. Putting $R \sim 10^3$ parsec, $N \sim 0.1 \, \mathrm{cm}^{-3}$, $f \sim 10^{10} \, \mathrm{c/s}$, $\Delta f \sim 10^6 \, \mathrm{c/s}$, we find $\Delta t \sim 10^{-6}$ sec, i.e., $f \cdot \Delta t \sim 10^4$.

However, given constant dispersion, this effect will not cause any fundamental difficulties: it merely amounts to a certain re-encoding of the transmitted signal by the medium. In other words, we have to break a different code, but this is clearly a meaningless point since the "initial" EC code is not known either. The situation is much worse if the dispersion has a substantial slowly varying component. In this case fundamental difficulties are encountered in the breaking of an arbitrarily variable code. The call signals can therefore be expected to be so devised that on reception they will reveal the key to the dispersive properties of the medium. This purpose can be achieved, say, with call signals comprising a train of quasimonochromatic pulses of different frequencies which cover at definite intervals the entire frequency range from $f - \dfrac{\Delta f}{2}$ to $f + \dfrac{\Delta f}{2}$ with a common amplitude modulation.

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*   This formula is valid only for comparatively high free electron densities, when $\dfrac{c}{f} \sqrt[3]{N} \gg 1$; for $\dfrac{c}{f} \sqrt[3]{N} \sim 1$ the dispersion is mainly attributed to the regions of locally increased concentration of electrons.

44

Bibliography

1. Kardashev, N.S. — Astronomicheskii Zhurnal, **16**:282. 1964.

2. Golay, M.I.E. — Interstellar Communication, p.192. N.Y. 1963.

DISCUSSION

V. A. Kotel'nikov. Broad-band spectra discussed by N. S. Kardashev are intended for very advanced civilizations. If we consider the question of transmitting a limited quantity of information, a narrower spectrum is surely more convenient. But in a narrow-band observations there is always the danger of missing the signal altogether. We should therefore employ a system of narrow-band filters which combine to give continuous coverage of the entire relevant region. I shall dwell on this point in greater detail in my paper.

Ya. B. Zel'dovich. It seems to me that this is quite unnecessary to attempt a transmission crammed with maximum information, which requires broad frequency bands and correspondingly high transmitter power. It suffices to send call signals which are quite adequate for detection. The very fact of discovering an extraterrestrial civilization carries an enormous quantity of information (specifically, that an extraterrestrial civilization exists, sends radio signals, etc.). In order to detect artificial sources, we should proceed with both angular and frequency scanning. We should look for monochromatic point sources.

A. A. Pistol'kors. V. A. Kotel'nikov, in his summary of the terms of reference of this conference, said that we are expected to discuss the probability of existence of extraterrestrial civilization and, once this probability has been assessed, to make a decision concerning the financial and the organizational aspects of a search for intelligent signals from space.

An alternative approach is also possible: we may start with the fact that mankind, at the present stage of development, has become interested in the problem of communication with other civilizations. Why did this interest arise? May be we need reassurance that man is not alone in the Universe; may be this is an instinctive wish to expand our knowledge, and may be this is a manifestation of a latent intention to profit by intercepting information transmitted by more advanced civilizations.

A new scientific trend is an established fact already. The historical example of cybernetics, which at first got a very skeptical reception, suggests that we should take this new trend more seriously. In my opinion, it deserves to receive all the possible support from this conference, as it is obviously one of the new scientific disciplines conc   ed with the conquest of space, such as the biology of space flight and some other branches of modern science.

Researches should be set up in order to detect meaningful signals, if any, from space and to reach definite conclusions concerning the existence of extraterrestrial civilizations.

V. I. Siforov. I second A. A. Pistol'kors's motion: the research into the problem of communication with extraterrestrial civilizations should be commenced as soon as possible and it deserves an all-sided support.

46

As regards the question of spectrum width, I also think that the sheer quantity of information is not of primary significance. We should look for artificial sources by examining their frequency, direction, and the shape of the spectrum. What is the optimal search program? I shall discuss this in more detail in my paper. The statistical structure of signals is clearly of the greatest significance. But the main searchlight should obviously be directed to call signals.

N. S. Kardashev. I would like to point out that observations seem to rule out the possibility of existence of advanced civilizations in the immediate vicinity of the Sun. This aspect of the problem cannot be ignored in future discussion.

V. A. Ambartsumyan. A paper read to us seems to suggest that the communication with extraterrestrial civilizations should be established by means of continuous, isotropic, and nonmonochromatic signals. On the other hand, it seems obvious that to ensure long-range communication against the background of cosmic noise, we should use narrow-band, beamed signals. Moreover, the monochromatic composition of the signal, supplemented by slow variation of frequency, is in itself adequate proof of artificiality.

I. S. Shklovskii. The question can be stated as follows: is a narrow beam actually suitable for searching for a few millions of correspondents? Present-day radio physics is unable to solve this problem within a reasonable time. We therefore concentrate on type III civilizations possessing energy resources on the galactic scale: they can transmit isotropically and thus send signals simultaneously to all prospective correspondents. In this way they can be fairly sure that their signals will eventually be detected.

As regards two-way communication, it is of course highly desirable, but impossible on account of the enormous distances.

Ya. B. Zel'dovich. Our task is now much simpler, since I. S. Shklovskii transferred the burden of establishing communication to other, more advanced civilizations, which control power resources of the order of 10^{33} erg/sec.

V. A. Razin. In my opinion, it is highly improbable that civilizations will develop to a stage when they have harnessed power resources on the galactic scale, of the order of 10^{44} erg/sec.

If intelligent beings occupy a galaxy in $\sim 10^6 - 10^7$ years, most of the galaxies should have been inhabited by now. This is obviously not so. The spread of intelligent beings in galaxies, if at all feasible, is apparently an extremely slow process. During the life of the visible part of the Universe ($\sim 10^{10}$ years), the different civilizations have apparently conquered but a negligible part of the $10^9 - 10^{11}$ planetary systems in their respective galaxies.

More probable is the existence of civilizations commanding power resources of $\sim 10^{24}$ erg/sec (the Earth receives from the Sun $\sim 2 \cdot 10^{24}$ erg/sec, and humanity at present consumes some $3 \cdot 10^{19}$ erg/sec). These civilizations are incapable of sending sufficiently powerful signals with an effective spectrum width of $\sim 10^{11}$ c/s. On the other hand, they may possess adequate technical means for sending very tight messages to large distances. Therefore, if we are concerned with detecting signals from extraterrestrial civilizations, we should first look for quasimonochromatic signals.

47

D. Ya. M a r t y n o v . Even if a type III civilization is inconceivably advanced, it seems hardly reasonable, if not outright improbable, that this civilization will waste such enormous quantities of energy in order to advertize the mere fact of its existence. The suggestion that this may be a byproduct of everyday activities does not answer the question: is it really necessary to convert all the dissipated energy to radio waves? Why and what for?

To increase the probability of establishing contact, one must know in what direction one should look for meaningful signals. The transmitting civilization should therefore make its existence known not by means of noise signals and not continuously, since this is a highly uneconomic, wasteful procedure (here I am of the same opinion as V. A. Ambartsumyan). As long as the location of the other side remains unknown, call signals must be anisotropic.

L. M. G i n d i l i s . The probability of detecting signals from extra-terrestrial civilizations is generally estimated on the conservative side. If the question is how to establish communication with civilizations of our or slightly higher level, the difficulties are indeed insurmountable: to ensure reasonable range of communication, the transmission should be made with tight, directional beams in a very narrow frequency band. But this restriction is by no means necessary. As long as we accept the fact that we are not the only civilization in the Universe, there is no escaping from the conclusion that highly advanced civilizations exist, as well as civilizations which are on the same evolutionary level as humanity, or even somewhat lower. The advanced civilizations, according to I. S. Shklovskii, may command gigantic power resources of up to 10^{33} erg/sec. This radically changes the situation.

If this energy is converted fully or partially to isotropic radio waves, the civilization will reach simultaneously all the subscribers inside the sphere of action of the transmitter. With powers of $\sim 10^{33}$ erg/sec, the sphere of action is sufficiently large to permit the luxury of sending in a broad frequency band, so that enormous quantities of information can be transmitted. If somewhere in our Galaxy, or even in other galaxies of the Local Group, at least one civilization of this kind exists, its signals can be detected by us now, at the present level of our technological development.

The problem of establishing communication with extraterrestrial civilizations, or speaking in radio-astronomic terms, the search for artificial sources of radio emission in space involves a dual uncertainty: uncertainty of frequency and uncertainty of direction. It is particularly significant that an objective criterion based on the actual spectral distribution of noise makes it possible to fix, although crudely but nevertheless with fair certainty, the region of the radio spectrum for meaningful communication (this is the region of centimeter and decimeter waves). Given a broad-band transmitter, we need not bother with exact centering of the receiver band.

Furthermore, antennas with effective surfaces of $10^4 - 10^5$ m^2, which are a must for the reception of information, are by no means essential for source detection. Sources can be detected with the much smaller existing antennas, with effective surfaces of the order of 10^3 m^2.

There is obviously not much to be gained by detailed inspection of each and every known and newly discovered radio source. A certain coarse

selection test should first be applied to sift the probable suspects from the total multitude of cosmic radio sources. The most convenient test in this respect is apparently provided by the angular size criterion. For example, the field can be limited to all sources measuring $< 0''.1$, regarding all sources $> 0''.1$ as of definitely natural origin. To this end, the entire sky should be surveyed with an interferometer having a resolving power of $0''.1$ and a sensitivity of up to 10^{-27} W$\cdot$m^{-2}(c/s)$^{-1}$.

The selected suspects should be carefully submitted to all the tests which differentiate artificial from natural radio sources. Some of these tests (ultimately small angular diameter $< 0''.001$, characteristic spectral distribution of power, circular polarization, time variability, peculiar features near $\lambda = 21$ cm) were proposed by N. S. Kardashev. In itself this is a highly valuable contribution which places the search for artificial radio sources on a sound scientific foundation. These criteria, of course are neither absolute nor single-valued. I should say that they are the sufficient conditions, i. e., if a certain source is found to satisfy all Kardashev's tests, then with a high degree of probability this source can be regarded as artificial, although some artificial sources may fail to satisfy one or even several of these criteria (with the possible exception of the angular size test).

These uncertainties create an actue need for the development of some general and absolute criteria of artificiality based, say, on the analysis of the statistical properties of the signal or the general theorems of the theory of information.

In conclusion I would like to consider another question. What is the expected number of artificial sources in our Galaxy? Let us assume, quite arbitrarily, that the number of type II civilizations in the Galaxy is 1000. It is hardly necessary for each of these civilizations to maintain a transmission service to the entire Galaxy: the duplication of effort is much too high. A more efficient approach is to charge one of the civilizations with the task of transmitting meaningful information, while all the others send call signals only. An alternative solution is the division of the entire Galaxy into "spheres of influence" with each supercivilization transmitting to a different population, while the most advanced civilization of the lot sends signals to other galaxies. This possibility cannot be ruled out a p r i o r i , and the estimation of the number of artificial sources is thus an intricate problem.

V. A. A m b a r t s u m y a n . I am also of the opinion that extraterrestrial civilizations should first advertize the very fact of their existence, i. e., send call signals. Transmission of information is a secondary matter. It is quite probable that call signals will be sent by transmitters of one kind, while the detailed information will be transmitted by signals of an entirely different kind. Call signals carry a small quantity of "tentative" information which has some bearing on the nature of signals transmitting the main information.

G. S. S a a k y a n . Speaking of communication with extraterrestrial civilizations, we should take sccount of possible differences between our subjective time and their subjective time. Indeed, some of these alien civilizations may exist under extreme physical conditions, e. g., in a strong gravitational field, in a rapidly rotating frame, or in abnormally fast translational motion.

E.G.Mirzabekyan. Communication with extraterrestrial civilizations is clearly a scientific problem. But given the present-day state of our technological development, our actual resources, it seems to me that the discussion is somewhat premature. Another point should be considered: our technological civilization occupies a very insignificant place on the cosmic time scale. A similar situation can be expected to obtain for other civilizations as well. In other words, simultaneous existence of several technologically advanced civilizations is highly improbable, and the probability of establishing communication with them is correspondingly low.

G.A.Gurzadyan. It seems to me that observations of radio sources in the continuous spectrum, as some of the colleagues suggest, will only reduce our chances of detecting an extraterrestrial civilization. The point is, that the continuous spectrum is a common feature of all celestial bodies which emit radio waves. In some cases, they even emit monochromatic waves at definite frequencies. A more logical approach to the search for extraterrestrial civilizations should therefore call for observations, not in the continuous spectrum, but at certain discrete frequencies which do not coincide with the frequencies of the known radio lines. If in this way we shall detect a signal, say, at a wavelength of 34 cm, while nothing has been detected at wavelengths shorter and longer than 34 cm, we can state with fair certainty that the detected signal is of artificial origin, since not a single body in nature emits monochromatically at this particular wavelength by any of the known physical mechanisms and phenomena. Reasoning along the same lines, our extraterrestrial correspondents will also prefer to transmit monochromatic radio signals. The entire question thus reduces to the optimal frequency for transmission. The observations should therefore be so organized that frequency scanning in the probable radio region is made possible. Silence in the entire region and reception of radio signals at some discrete frequencies will provide an indication of artificiality.

D.Ya.Martynov. The monochromaticity criterion should be considered with great caution. In some cases, stellar outbursts are confined to a very narrow frequency band. This does not mean, however, that these signals are artificial.

Ya.B.Zel'dovich. High-altitude nuclear explosions generate intense electromagnetic radiation which in some cases is more powerful than the radiation of terrestrial radio stations and, in principle, can be detected at an interstellar range. Attention should therefore be paid to other modes of signal generation.

As regards G.S.Saakyan's observation on differences in subjective time in other planetary systems, strong gravitational fields can indeed alter the flow of time. But extreme gravitation at the same time will seem to rule out the very possibility of life.

Yu.N.Pariiskii. We tried to detect circular polarization in the radio waves of CTA 21 and CTA 102. As a preliminary observation, I can say that it does not exceed 50%. I think that conclusive results will be available in two months' time.

P.M.Geruni. The Earth civilization is very young. Its technological resources are hardly up to the task of establishing communication with other civilizations. Besides the technological aspect, there are many other no less important facets to this problem. Identification, linguistics, information exchange, all these topics have to be considered in the

greatest detail. I should like to discuss briefly the question of expediency. Alien civilizations picking up our transmission may have aggressive tendencies. It is in this sense that we shall speak of "healthy" and "unhealthy" civilizations.

Since our civilization is very young, our first contact in all probability will be made with more advanced civilizations. Civilizations which have reached a high level of development can be expected to be healthy. Anyhow, a healthy period should be the longest in the civilization's life span, excepting of course the initial formative period and the stage of destruction. It should also seem that a healthy civilization will attempt to establish two-way communication with other civilizations, to gain new knowledge and to allow others to profit by its knowledge (this also rules out the possibility of aggression).

All this implies that in devising techniques and tools for communication with extraterrestrial civilizations, we should concentrate on both reception and transmission. Moreover, transmission of information is properly considered a duty of any more or less advanced civilization.

Another aspect to be taken into account at the planning stage is the life span of successive generations of the alien civilization. Differences in this factor may prove to be quite significant.

Even on the Earth, where life has developed under comparatively uniform conditions, the life span of different organisms ranges from a few minutes to hundreds of years. This question is of great importance in connection with the choice of modulation frequencies. Modulation period and the period of signal repetition should be apparently much less than the life span of the particular organism. Otherwise, our signals may go by unnoticed, ignored as having an insignificant information content, or even classified under the category of signals which do not satisfy artificiality criteria. Civilizations are of course equipped with technical means for recording signals whose periodicity varies between very wide limits. This, however, does not detract from the significance of the point mentioned above (especially in the case of call signals).

The transmission should consist of call signals followed by an elementary message. To ensure energetically high spectral density, we are forced to transmit in a comparatively narrow band, which inherently limits the information capacity of the channel.

It seems that in the first stage we are not expected to send great quantities of information. It should be remembered that the call signals themselves carry some information, as well as the message proper. Development of efficient call signals is a highly important stage in this work. The call signals should be powerful and they should be transmitted in different directions at fixed, constant intervals, at different frequencies in broad and narrow bands.

Reception should be attempted on a larger basis. The receivers should be tuned to different frequencies, using beamed antennas pointed in the most probable directions.

The most convenient working frequencies are apparently in the region of centimeter and decimeter wavelengths. This region is also optimal as regards absorption in the interstellar medium.

Receiving antenna arrays should have high sensitivity, i.e., large effective surface. We know that two-mirror systems with a stationary

main spherical mirror are highly effective and involve minimum capital outlay per unit aperture area. Automatic tracking of the source should also be ensured. Two-antenna arrays, e.g., the BDA, are ideally adapted to this purpose. To ensure high sensitivity, the antenna array should have low set noise. The set noise of the BDA should not exceed $10-15\,°K$.

N.S.Kardashev. The opinions varied in the course of this discussion. Some of the colleagues suggest that, as a first stage, we should concentrate on "supercivilizations" which are capable of sending continuous and isotropic transmissions in a broad frequency band. Others maintain that we should only look for civilizations whose technological level is similar to that of the Earth. The radiation in question is therefore expected to be beamed, with a narrow frequency band, the transmitter sending very brief signals in each direction.

I would like again to emphasize that on account of enormous differences in star ages, which are measured by billions of years, a "supercivilization" is the most probable candidate for first contact. Nonexistence of "super-civilizations" would imply exceptionally low probability of the evolution of life, or some fundamental restriction of evolution, and this progressively reduces the chances of detecting a civilization on our level.

It is apparently advisable to start looking in both directions in parallel. However, the search for radio signals from "supercivilizations" is a technically simpler task. As a first stage, a complete radio-astronomic survey of the sky should be made in the centimeter range with an interferometer having a lobe width of $\sim 0''.1$ and a limiting sensitivity of $\sim 10^{-27}\,W \cdot m^{-2}(c/s)^{-1}$. This survey can be completed in the next few years. More complex equipment should be developed in the meanwhile, permitting detection of monochromatic radiation from objects within a radius of, say, 1000 light years.

COMMUNICATION WITH EXTRATERRESTRIAL CIVILIZATIONS

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The analysis of the problem of radio communication with extraterrestrial
civilizations leads to the conclusion that any form of radio contact with
alien civilizations of approximately the same level of development as the
Earth civilization is highly improbable. The chances of establishing
communication with much more advanced alien civilizations (always
assuming that these civilizations do exist) are considerably better. The
first question to be dealt with is concerned with the technical resources
available to the advanced civilization. The only reliable answer to this
question is that these resources can in no way exceed the limitations set
by the laws of nature. At a first glance, this trivial proposition does not
help us with our problem. However, one of the most significant questions
of interstellar communications is how to dissociate the artificial signals
of the different communicants from natural radio emissions; but as long
as the radio waves emitted by all the natural radio sources whose power
is comparable with the expected power of artificial signals have not been
studied in the greatest detail, the only observation that can be made on
artificial radio signals is that their existence is compatible with the laws
of nature. Therefore, the only indisputable proof of artificiality is the
detection of some information which is beyond the scope of the intrinsic
information contained in the radio waves of natural sources, such as
information on the power of the radio source, its spectral composition,
polarization of radiation, source diameter and distribution of brightness.
But this "natural information" contained in any kind of radio waves, both
natural and artificial, provides at most a suspicion of the source's artificial
origin, in no way offering a conclusive proof of artificiality. This suspicion
can be considered well founded only if the number of sources (either natural
or artificial) for which "natural information" is available is considerable and
if this information is substantially comprehensive. The accumulation of
extensive "natural information" is obviously the task of radio astronomy.
Hence it follows that systematic search for radio signals from extra-
terrestrial civilizations (and not such discoveries as may conceivably be
made by chance) is fully within the original scope of radio astronomy up
to the moment when sufficient "evidence" has been collected on the artificial
origin of some source or sources. It is only at that moment that efforts
should be made to detect information in excess of the "natural information"
of the signal. This is the specific problem of interstellar communications,
and its solution requires special technical tools which are not employed

in conventional radio astronomy: receivers of ultimate sensitivity will be needed, which ensure continuous coverage of the entire frequency range suitable for interstellar communications, i.e., the wavelength range from 50 cm to 3 cm, if the receiver is located on the Earth's surface (under the atmosphere). Radio astronomers, on the other hand, do not require more than a few high-sensitivity wide-band receivers distributed more or less uniformly in the relevant frequency range, without ensuring complete frequency coverage.

In planning to make contact with more advanced civilizations, we can add nothing definite to the above seemingly trivial contention concerning the inherent limitations of these civilizations. Various speculations on the resources and skills of advanced civilizations which have been published in various sources are highly dubious, although they differ in their credibility (it should be borne in mind, however, that this "credibility" is assessed on the basis of our terrestrial notions). There is but one fairly certain proposition that can be additionally made. The feasibility of interstellar communication depends on the technological resources of the two communicants; it is determined by the "product of these resources". If we employ exceptionally powerful receiving equipment, the other side may transmit at a low power level over enormous distances, and communication is still possible. The application of powerful means on the Earth therefore considerably increases the probability of establishing interstellar contact, and this point must not be ignored. (The question of "terrestrial technology" and what it can achieve will be discussed in greater detail in what follows.)

In discussing the problem of radio communication with highly advanced extraterrestrial civilizations (we call them A civilizations), we find ourselves in a very difficult position, as nothing definite is known on the technical resources of A civilizations. These advanced civilizations are in a much more favorable position, since in planning to establish radio communication with an inferior civilization (a B civilization), the A civilization knows precisely what is the lowest level of development of the B civilization at which the latter will be able to detect the former's meaningful signals and to decode the message. If we accept this certainty, we can make an educated guess as to the plan of action which is probably adopted by the A civilization.

In the following, we therefore reason as representatives of an A civilization assuming that they, as we, have reached the conclusion that a multiplicity of civilizations at different stages of development exist in the Galaxy (the A civilization by assumption being part of this extensive "membership"). What course will the A civilization take in order to make contact with a B civilization in the shortest possible time and with the highest probability of success? Is it reasonable to expect that the A civilization will begin an isotropic transmission ("calling all the Galaxy") without first trying to establish whether at least one B civilization exists in the Galaxy, and if it does, then in what particular part of the Galaxy? This is of course the simplest, but the least reliable course of action open to the A civilization, if there were absolutely no way to establish the existence, or otherwise, of B civilizations. But the point is that A knows the minimum required level of development of B (all civilizations below B level are ignored by A, since they are incapable of receiving

54

the transmitted information). Proceeding from this datum, A will reason that B is capable of giving some sign of its existence and its readiness to receive information from a more advanced civilization.

To make the point more tangible, let us assume that the minimum level of development required by A is close to the present stage of our civilization. (If it is much higher, we are unable to take part in the communications program under discussion.) Then B is in a position to transmit monochromatic signals with a line width of a few cps or tens of cps at the rated frequency of neutral hydrogen or, which is even better, at one of its higher harmonics (apparently not above the fifth), with a power of thousands of kilowatts, in a cone with a solid angle of a few tens of square seconds of arc. The orientation of the cone axis should be varied regularly according to a pre-selected program so that in a comparatively short period (a few years at most) the cone will have scanned the entire solid angle where most of the stars of the Galaxy are concentrated. Since A is convinced that B will send this "ready signal", special equipment will be built by A to pick it up. In addition to conventional tools, which are possibly also known to B, A will have to create radio telescopes of high surface efficiency which moreover have a sufficiently large beam width (that this problem is solvable in principle we see already from the fact that optical systems with these properties are in common use). Wide-angle radio telescopes will ensure rapid detection of the "ready signals"; they will also permit determination of the angular size of the star associated with the B civilization and estimation of the distance to that star. All this can be done by analyzing the very slow and uniquely decodable manipulations to which the monochromatic signal is subjected at the origin by B. After this A can immediately start transmitting in a tight beam directed at B; the message should be provided with a pilot signal at the frequency of the "ready signal" sent by B (to forewarn that the transmission contains "artificial information").

This approach to interstellar communications of course postpones the first transmission of information from A to B by a number of years which is equal to the distance from A to B in light years. But can we be sure that by disposing with this system we advance the time of the first reception of information? In other words, we should decide whether by sending "ready signals" B actually advanced the time of the first reception of information from A. The answer to this question depends on the behavior of A. If it persists in its attempt to transmit information to B civilizations which do not send "ready signals", it may proceed in two ways: the first possibility is to create isotropic transmitters and to increase the transmission power correspondingly (in order to ensure constant energy flux density, since any reduction in flux density raises the minimum level of development of B). The power should be increased by a factor of $10^6 - 10^7$ (the ratio of the solid angle containing most of the stars in the Galaxy to the solid angle of a tight beam in which the entire energy can be concentrated if the position of B is known). But the energy resources of A can be increased by a factor of $10^6 - 10^7$ in no less than a millennium (this is the most optimistic estimate given by various authors), so that the earliest time of information transmission from A to B is automatically postponed at least by a thousand years.

Another possibility open to A is to send a tight beam which is made to "sweep" a cone containing most of the stars in the Galaxy. Since the solid

angle of this cone is approximately 10^6 times as great as the beam width, the probable delay between the start of transmission by A and the first reception by B will increase roughly by the same factor. Thus, if the distance between A and B is less than a thousand light years, transmission of "ready signals" definitely advances the time of first reception of information from A by B.

This bilateral program for establishing communication between civilizations A and B cannot be "coordinated" with A, but if we agree that this is the most reasonable approach to the concept of joint effort, then civilization B should clearly carry out in great detail each and every operation prescribed by our plan. Otherwise, we face the danger of wasting in vain all the efforts and the resources which were required to complete part of the stages in the plan. This danger, of course, exists even if B closely conforms to the plan, but it is particularly great if no "ready signals" are transmitted. To visualize the exact nature of this danger, we should take account of the fact that the Galaxy is probably inhabited by several civilizations of the B level. If our plan is indeed the most reasonable, other B civilizations can be expected to adopt it, the transmission of "ready signals" included. But then A will only concentrate on those B whose "ready signals" have been picked up. The "nontransmitting" B will thus be in the worst position as regards communication with A among the other B. If B civilizations were inherently incapable of sending "ready signals", A would adopt the only remaining course and transmit to "all the Galaxy" (either by a special isotropic transmitter or by a narrow "Galaxy-scanning" beam), so that all B would be in the same position. But if B are capable of sending "ready signals", and only one of them has chosen to ignore this possibility for some reason, its position is much worse than that of the others. A curious situation thus obtains: in the "Universal community of civilizations", each civilization having reached a certain stage in its evolution must devote some of its efforts to strengthening the "community". If it ignores this duty, it is in the danger of being bypassed by the mainstream of civilizations.

This situation should be taken into consideration when the intercivilization distances are large — a few thousands of light years. Civilization B is capable of sending "ready signals" over this range, too. But as we have seen in the preceding "ready signals" in this case cannot speed up the reception of information from A, and yet a "nontransmitting" B may find itself at a disadvantage in relation to those B which do send "ready signals". However, the question of large intercivilization distances requires a more detailed consideration. The point is that, given widely separated civilizations, the "ready signal" sent by B may remain long enough en route for the signaling civilization to have evolved from class B to class A by the time the "ready signal" is picked up by some A. In other words, our civilization will have developed to such an extent that, besides being able to receive information from a more advanced civilization, it may also start transmitting information to more primitive civilizations.

However, as long as the distances between neighboring civilizations do not exceed a few hundreds of light years, the civilizations can hardly make a cardinal step along the evolutionary ladder during the signal propagation time. Anyhow, this possibility is ignored.

As long as we are dealing with moderate distances (a hundred — two hundred light years), the above arguments provide the necessary data

for outlining the steps to be taken by our civilization — as a type B civilization — and the technical tools to be developed for purposes of interstellar communications.

It follows from the above that interstellar communication is a problem which should be solved by the concerted effort of many generations working according to a uniform systematic program. It may happen, of course, that the first success will come pretty soon, but this is fairly improbable and the program should be designed for long years of patient, systematic work. The attempts to reach the ultimate aim with very limited means, such as the Project Ozma, though not entirely without justification, cannot be considered as the first stage in a systematic program. These attempts are of any recognizable value only if they do not divert means and efforts necessary for setting up regular, systematic work on the problem. Limited experiments can be continued in future with the aid of existing or projected radio telescopes and other instruments, but systematic work is impossible without drawing upon the entire technological reserve of our civilization.

As we have observed, the first and decisive stage in the program — detection and investigation of a maximum number of faint discrete radio sources — coincides with the fundamental task of radio astronomy. The proposed survey requires a radio telescope of maximum surface efficiency and resolution, with receiving equipment of maximum sensitivity. Both the radio telescope and the receivers should be adapted to operate in the entire range of wavelengths expedient for interstellar communications, i.e., roughly from 3 to 50 cm. The effective surface of the radio telescope should be at least $100,000 \, m^2$, its resolution not less than $1-2''$ (at 3 cm). Since the central part of the Galaxy (where most of the stars are) is obviously the most promising as far as the search for artificial radio sources is concerned, the design work can be simplified by making the radio telescope partly steerable: it need only scan the region from 0° to 30° above the horizon (the radio telescope site is assumed to be located at a latitude of some 45°) and between azimuths of $\pm 30°$ from the meridian. Furthermore, in the first stages, when we are concerned with simple detection of artificial sources, and not reception of complex information, automatic tracking is not essential: it suffices if the radio telescope can be pointed quickly to any point within the above field. All this considerably simplifies the design of the radio telescope and particularly its auxiliary mechanisms, so that the cost of the auxiliary equipment and control instruments is no more than a small fraction of the total capital outlay. The cost of this radio telescope thus mainly depends on the cost of manufacturing and assembling a large high-precision collecting surface. The broad wavelength region required for the task on hand can be attained only with a reflector radio telescope, while the high resolving power is possible only if the horizontal dimension of the reflector is much greater than the vertical dimension. Two of the existing systems meet both these requirements: the Pulkovo variable-profile antenna (VPA) and Kraus's modified radio telescope, now under construction at Nançay. However, the VPA has a single reflecting surface made up from individual moving elements (plates), while Kraus's system employs two reflecting surfaces, one fixed and the other made up from moving elements (the plate driving mechanism here is somewhat simpler than in the VPA). Since for limited plate displacements, the cost of the radio telescope mainly depends on the

cost of building the high-precision reflecting surface, VPA is approximately twice as cheap as Kraus's modified system of equal reflector area and resolution. The VPA system thus seems to be eminently suitable for our purpose. Preliminary calculations have shown that a VPA radio telescope meeting the above standards is quite feasible, since its construction does not involve any fundamentally new technical problems. In short, we can begin building this telescope even today.

A VPA radio telescope incidentally solves the problem of the antenna for transmitting "ready signals", as its antenna can be adapted to radiate high-power signals at any wavelength of the relevant range.

The VPA radio telescope thus completely solves the problems encountered in the first stage of the program. We must not neglect the possibility that already in the first stage of work we shall have to start estimating angular diameters of radio sources smaller than $0''.1$ (the VPA with a resolving power of $1-2''$ will measure angular diameters higher than $0''.1$). This requires radio interferometers with very large bases, but the surface area can be somewhat less than that of the VPA (since the existence of very powerful artificial radio sources is highly improbable). The most efficient course is therefore to build an interferometer with the VPA as one of its antennas; the other antenna can of course be much smaller, as long as the radio sources are sufficiently powerful.

It should be noted, however, that the question of the minimum angular size that can be measured under normal atmospheric conditions of the Earth (in particular, in the presence of atmospheric turbulence) is by no means clear. In order to elucidate this problem, and also to determine the size of the "suspects" (if their power flux is not exceedingly small), we suggest a combination of existing radio telescopes into interferometers with extraordinarily large bases — of the order of 10^6-10^7 wavelengths. A suitable provision should be made for this work in the overall program.

The general plan should also provide for the development of a selection of wide-band receivers with a minimum level of set noise and of low-noise components for the high-frequency channel. (The methods of analysis of signals at the output of wide-band receivers and the apparatus required for this purpose provide ample ground for a special conference, and we therefore do not propose to go into this subject here.) Finally, powerful transmitters of "ready signals" should be developed, meeting very rigid standards as regards frequency control. This is a difficult problem which still remains unsolved to a considerable degree. Its solution is apparently simplified by the fact that these transmitters need not be modulated (the manipulations of the signal that we have mentioned above are performed with the antenna pattern; they do not affect the transmitter).

The development of the specialized equipment should be left to the most qualified institutes of our national academies of sciences and to state committees on radio electronics and electronic engineering.

CONCLUSION

The characteristic feature of the problem under discussion is that it aims far into the future. Without being over-optimistic (which is more

harmful than helpful in this case), we must say that the results of this work will become available to our descendants and possibly even to their descendants. The final outcome, however, cannot be negative. Even if for many centuries no contact will be made with an extraterrestrial civilization, this will only mean that in a certain nearby region of the Universe there are no civilizations more advanced than we of the Earth. (This peculiarity may possibly receive some sort of an explanation as our knowledge of the Universe improves.) But by the time this "flattering" fact becomes known, our civilization will have advanced so far that it should be able to transmit information to more primitive civilizations.

The activity of the Earth civilization in this direction will not cease, since it will be in a position to assume the "duties" of a type A civilization. In our opinion, this activity can hardly stop as long as more or less advanced civilizations exist.

The problem under discussion is not the only one which does not give immediate results during the lifetime of one individual or one generation. As humanity advances into the future, other problems of this kind will arise: it will be impossible to set a definite time limit for the solution of the problem, the first real success may come quite unexpected and even pass by unrecognized, and failure to achieve outstanding results need not be interpreted as a sign that further efforts in that direction should be discontinued. (I would like to emphasize that I do not mean the development of science in general, where such situations are fairly commonplace, but definite applied problems.) It is obvious that as new problems of this kind crop up, we shall get used to the unusual flavor. We should not ignore the fact, however, that at present this situation is both novel and strange, it involves a considerable psychological difficulty for us, which is particularly acute in the first stages of the research program. To overcome, or at least to cushion, this difficulty, we should focus our attention on the identity of interests between conventional radio astronomy and the first stage in the problem of interstellar communications. Because of this aspect, the preliminary work can be so organized that it should yield tangible results from the very start, thus justifying the human effort and preventing unnecessary frustration from spreading among the many rank-and-file who of necessity will have to be employed together with the few enthusiasts. The success of the first and of all the subsequent stages in the program will depend, in my opinion, on our resourcefulness in handling the tricky situation as I have described it here.

A RING RADIO TELESCOPE FOR COMMUNICATION
WITH EXTRATERRESTRIAL CIVILIZATIONS

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It is apparently obvious that at this stage of development, our attempts to establish communication with extraterrestrial civilizations are confined to passive listening to radio signals transmitted by more advanced civilizations. Dissociation of the artificial signals from the natural background radiation requires radio telescopes of high resolving power. On the other hand, narrow antenna patterns are possible in large radio telescopes only; this involves great structural difficulties and, which is no less significant, a disproportionate increase of cost.

The search for extraterrestrial civilizations should be apparently made according to a special program, which will engage the radio telescope for a fairly long time. The ring radio telescope (see Soobshcheniya Byurakanskoi Observatorii, No. 36) can thus be recommended for this purpose, as it permits simultaneous and independent observations in several different directions.

The antenna has been considerably simplified in the ring radio telescope, and this reduced its cost substantially. On the other hand, the ring telescope with its knife-edge pattern ensures high resolution in the two coordinates.

The ring radio telescope is a two-reflector antenna array, where the main reflector is a stationary spherical ring of large diameter and comparatively small width whose surface makes a certain small angle with the vertical. The sky is scanned by moving the second small correcting reflector along the focal line of the main ring. The second reflector is fairly low, and it can be moved along a circular rail track without much difficulty. (The cost of the ring reflector is comparable to the cost of a variable profile antenna of equal area, minus the plate tilting mechanism; the fixed plates of the ring reflector are of course easier to adjust than the articulated plates of the VPA.)

As with an ordinary two-reflector antenna array, only part of the ring with an aperture of some $0.6-0.7$ of the ring diameter can be illuminated, which ensures a sufficiently narrow horizontal antenna pattern. The horizontal aperture of the second reflector should measure $0.07-0.1$ of the ring diameter. The height of the correcting mirror is a few meters.

Aside from being simple and cheap, the ring radio telescope permits simultaneous and independent observations in 20 different directions and can solve a great variety of radio-astronomical problems. This versatility is achieved by setting up to 20 correcting mirrors along the rail tracks.

Several secondary reflectors of the ring radio telescope can thus be engaged on the problem of artificial radio sources, while the other minor reflectors continue with routine radio astronomic research.

SOME CONSIDERATIONS ON THE SEARCH
FOR INTELLIGENT SIGNALS FROM SPACE

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INTRODUCTION

The problem of the search for intelligent signals from space has been repeatedly considered in literature /1, 2, 3/. The aim of our communication is to evaluate the present-day situation as regards the probability of detection of signals from space, sent by intelligent beings for purposes of establishing communication and giving notice of their existence. It is of course insufficient to consider the different aspects of reception without paying any attention to transmission, since the latter in fact decides the properties of the received signal. We should therefore consider the entire complex of transmission-reception problems, i.e., the general problem of communication. The basic task here is to determine the optimal conditions of reception and transmission to be attained by both sides. In the following we discuss the most expedient forms of artificial signals and the techniques of their detection. Some aspects of communication with our nearest stellar neighbors are considered.

1. Expected form of artificial signals

We start with the assumption that there are sufficiently advanced civilizations existing in the Universe which are capable not only of receiving various artificial signals, but also channelling off enough power for the transmission of strong radio signals. What is the most probable form of meaningful signals that can be expected? In general, we can answer this question only on the basis of the present-day state of the Earth civilization and technology. However, despite this obvious restriction, the artificial signal should meet two quite general requirements:
    1. The signal should not leave any doubt as regards its artificial origin.
    2. The signal should carry some information concerning the transmitting civilization.
It should be remembered, of course, that on account of the enormous distances in the Universe the communication is liable to be mostly one-way. As regards the nature of the signal, we will consider electromagnetic signals only: at present, introduction of any other signal into the discussion will be sheer guesswork. To meet the first requirement effectively, the

artificial signal should be distinctly different in its properties from natural electromagnetic radiations. Monochromatic signals are obviously the most suitable in this respect. Monochromatic radiations are generally generated on Earth with the aid of special self-oscillatory systems which are mostly designed on the feedback principle. Although natural sinusoidal oscillatory processes are a fairly common occurrence, the resulting signal is much less ordered than the output of artificial oscillators due to random interference from nearby systems (in particular, the atoms and the molecules of the material medium) and thermal motion. The spectral line width of quartz and molecular generators at centimeter wavelengths, for example, may be as narrow as a few hundredths of a c/s /4/. An ordinary centimeter wavelength klystron or magnetron generator has an intrinsic line width of the order of 1 c/s (due to shot noise) /5/. The relative line width is thus of the order of $10^{-10} - 10^{-12}$. On the other hand, the relative line widths of natural sources in the optical range hardly ever reach the figure of 10^{-9}, even if special favorable conditions are satisfied; the common line widths are mostly of the order of $10^{-6} - 10^{-7}$. In the range of radio waves, even the monochromatic radiation of interstellar hydrogen (an extremely rarefied gas medium) occupies a band some $5 \cdot 10^4$ c/s wide (relative width $\sim 10^{-5}$). A very narrow-band radio signal with a relative line width of the order of $10^{-10} - 10^{-11}$ is therefore most suitable. However, since no information can be transmitted without signal modulation, which invariably broadens the frequency spectrum, the modulation should be sufficiently slow, say, no more than one bit per second, or even less. This of course reduces the information rate of the signal, but as long as the transmitting civilization is not sure that the receiving side has detected the signal and established its artificiality, there hardly seems to be much point in trying to transmit a maximum quantity of information. This course would be understandable only in the case of a hypothetical type III civilization /3/ with transmitter power sufficient to ensure reception virtually in the entire Universe. We, however, shall consider civilizations approximately on our level of development, and as will be seen from what follows, at this stage there is not much hope of establishing communication with civilizations distant more than 1000 light years from us.

The next characteristic feature of artificial signals is the modulation, the actual form of the signal. The requirement of slow modulation can be supplemented by a requirement of quasiperiodic modulation, which is achieved by repeating the transmission. The modulation should be made distinctly different from all the natural modulations. Square-pulse modulation is apparently the best for this purpose.

The creation of powerful monochromatic generators is a difficult undertaking, and we should not ignore the possibility of harnessing natural sources of electromagnetic radiation with continuous or fairly broad spectra. The modulation alone is then relied upon to provide all the necessary artificiality criteria. A conceivable approach to this problem is the creation of something like Dyson's sphere around the primary, with electrically controlled transparency for signal modulation. This obviously solves the problem of powerful signal generation: the power is there, and it should only be modulated intelligently. Efficient modulation is of course a problem by itself, possibly much more complex than the previous problem of setting up high-power transmitters. As regards the possible existence

of other constant powerful noise sources, which could conceivably compete
with the artificial sine-law oscillator, we can only say that no such noise
generators are as yet known on Earth.

A sinusoidal signal can be filtered from noise, as well as generated
by feedback oscillators. Although the two signals will have identical
spectral properties, their statistical behavior, e.g., the amplitude
distribution, will be entirely different. The amplitude probability distribu-
tion of a sine-law generator is peaked $V = V_0$, where V_0 is the mean
amplitude, while the probability distribution of the noise signal is peaked
at $V = 0$, the amplitude probability varying according to Rayleigh's
distribution. This, as we know, leads to random amplitude modulation and
the detector output delivers noise with a band width of the same order as
the spectral line width.

Special care should thus be taken to preserve all the distinctive statistical
features of the artificial signal, as well as its monochromaticity. We should
also study the influence of the interstellar medium on phase and amplitude
fluctuations of a monochromatic signal and on its polarization.

In this paper, we do not consider the effects attributable to signal
propagation conditions. We do not consider the possibility of using optical
generators, either: the discussion is confined to the radio wavelengths only.

The requirement of achieving maximum receiver sensitivity, and thus
a maximum transmission range, for a given transmitter power is also found
to lead to a sinusoidal signal. We now consider in some detail the optimal
conditions of transmission and reception.

2. General relations

We give here the known relations between range, power, and sensitivity
in the general case of directional (beamed) transmission and reception.
Let P be the transmitter power in watts, D_1 the directive gain of the
receiving antenna, D_2 the transmitting antenna gain, P_n receiving antenna
noise reduced to the input, and l the distance between transmitter and
receiver. If the received signal exceeds the set noise by a factor of n,
the minimum signal power at the antenna output should be $P_s = \sigma_1 S_m = P_n n$.

Inserting for the signal flux $S_m = PD_2/4\pi l^2$, and for the effective antenna
surface $\sigma_1 = D_1 \lambda^2/4\pi$, we obtain the required expression

$$\frac{P}{nP_n} = (4\pi)^2 \, 10^{32} \frac{l^2}{\lambda^2 D_1 D_2} \tag{1}$$

(l is expressed in light years, 1 light year $= 9.5 \cdot 10^{15}$ m). Or, expressing
D_1 and D_2 in terms of effective antenna surfaces,

$$\frac{P}{nP_n} = 10^{32} \frac{l^2 \lambda^2}{\sigma_1 \sigma_2}, \tag{2}$$

where λ is in meters, P in watts, σ in m^2.

This expression seems to suggest that the power P and the surface σ
both depend on l. Indeed, at large distances, comparable with the size of

the Universe, P and σ correspond to a time l light years in the past, when the civilization was less advanced than it is now. Taking account of technological progress, we should take $P=P(t-l)$, $\sigma(t-l)$, etc., so that P and σ are taken for the time when the signal was actually sent. Over small distances, however, which are much less than the radius of the Universe, differences of a few hundred thousands of years can be assumed due to inevitable fluctuations in the rate of evolution in various parts of the Universe. We shall assume that at any time during the last few millions of years, a whole evolutionary range of civilizations from the very young, like ours, to very advanced ones, in or even already past their prime, inhabited the Universe. The immediate dependence of P and σ on range in relations (1) and (2) is therefore ignored.

Let us estimate the optimal wavelength. We should take account of the dependence $P_n(\lambda)$ and of the maximum values of $\sigma(\lambda)$ and $P(\lambda)$ attainable under Earth conditions. While the function $P_n(\lambda)$ is virtually universal, being the same for all the civilizations, $\sigma(\lambda)$ and $P(\lambda)$ depend on the level of advancement and the local conditions of each civilization (force of gravity, material resources, etc.). On the Earth, we now have $\sigma \sim \lambda^{\prime\prime}$. The maximum power $P \sim \lambda$. Therefore, from (2) we see that the maximum l essentially depends on the minimum $P_n(\lambda)$. The noise minimum is fairly broad and shallow /7/, extending over centimeter wavelengths and the short-wave part of the decimeter range, approximately between 1 and 30 cm. If we assume that the peak power P is wavelength independent, the optimal range shifts in the direction of millimeter waves. If we remember however, that in the now available systems the noise is substantially higher than the background minimum, we conclude that millimeter and centimeter wavelengths are the optimum for transmission. In this case $l^2 \sim \lambda^{-1}$.

3. Optimal signals and reception

To choose the optimal signal, we should consider the behavior of P_n in greater detail. Take a receiver with an input band Δf and a detector whose output is coupled into an RC smoothing filter with a passband ΔF. The equivalent noise power of this amplifier is

$$P_n = kT\sqrt{\Delta f \Delta F} = \frac{kT}{2}\sqrt{\frac{\Delta f}{\tau}}, \tag{3}$$

where k is Boltzmann's constant, T the total noise temperature of the amplifier and the antenna. For the RC filter, $\Delta F = 1/4\tau$, where $\tau = RC$ is the filter time constant (integration or smoothing time). The time constant specifies the minimum time required to make a single measurement, and therefore it may be called the measurement time. Relation (3) is quite general. It can be shown to apply to the output noise for any technique of signal-from-noise separation in a band Δf with an integration time (e.g., recording time) τ.

Let us consider two extreme cases of transmission: 1) a sinusoidal carrier, and 2) a wide-band continuous-spectrum carrier.

In the first case, as we see from (1) and (3), it is advisable to reduce the reception band Δf and to increase the time of observation. In the

second case, we shall assume that the same transmitter power as in the first case is distributed in a band $\Delta\Phi$ with a spectral density $P/\Delta\Phi$. In (2), the power P is therefore replaced with the power falling in the receiver band, i.e., $P' = P\Delta f/\Delta\Phi$. This is clearly less than P if $\Delta f < \Delta\Phi$. By increasing the receiver band Δf to $\Delta\Phi$, so that the entire transmitted spectrum is picked up, we inevitably raise the threshold signal to $P_n = kT\sqrt{\Delta\Phi\Delta F}$, which is greater than the threshold signal in sine transmission by a factor of $P_n/P_n = \sqrt{\Delta\Phi/\Delta f}$. The "spreading" of the transmitted signal in a relatively broad range of frequencies is thus unfavorable from the energy standpoint.

Δf should be greater than the transmission band also when transmitting a monochromatic manipulated signal. It is therefore generally advisable to use narrow-band transmitters. The transmitter band should be chosen proceeding from considerations of the rate of information transmission and from the possibilities of frequency stabilization. We thus see that transmission of a monochromatic signal with a fairly slow modulation is most favorable from both energy and artificiality considerations.

The receiver band Δf is mainly limited by the available frequency-control techniques. Sinusoidal signals can now be received in a very narrow pass band, whose width is equal to one half of the drift in the central frequency of the local oscillators, i.e., $(10^{-8} - 10^{-9}) f_0 \sim 1 - 5\, c/s$. The noise temperature of receivers in the centimeter and the decimeter range can be made less than $100\,°K$. If we take $T = 70\,°K$, $\Delta f = 10\, c/s$, $\Delta F = 0.1\, c/s$, then

$$P_n = 10^{-21} \text{ watt.}$$

Unfortunately, no receivers have been built yet possessing the above noise temperature and the high frequency stability in a narrow band of a few c/s required for sinusoidal signal detection. There are, however, band readiometers from 7.5 to 60 cm with a band width of some $10^6\, c/s$ and a sensitivity of nearly $1°$ for a 1 sec integration time. These receivers will pick up both monochromatic and noise signals. Let us consider their intrinsic capacity.

The noise level at the radiometer output is also given by (3). For these radiometers, $\Delta f = 10^6\, c/s$, $T = 1500\,°K$, and $\sqrt{\Delta f\Delta F} = 10^3\, c/s$. We see that the radiometer noise power is greater by a factor of $20 \cdot 10^3 = 2 \cdot 10^4$ than the noise power of the narrow-band receiver considered above. To retain the previous range of communication with this radiometer at the receiving end, the transmitter power should be increased by more than a factor of 10^4. The search for sinusoidal signals should obviously be made with a tunable band receiver. The rate of scanning of a given frequency band is another important problem to be considered. In principle, a frequency band Δf equal to the receiver input band should be scanned in a time not less than the output filter time constant τ. The frequency band that can be scanned in a time t is thus

$$\Phi = \Delta f \frac{t}{\tau} = \frac{P_n^2}{(kT)^2} t.$$

The higher the receiver sensitivity (i.e., the smaller the factor $\sqrt{\Delta f/\tau}$ in (3)), the smaller the band that can be scanned in a given time. In our case, with $\Delta f = 10\, c/s$ and $\Delta F = 0.1\, c/s$ ($\tau = 2.5\,\sec$), a $10^8\, c/s$ band is

scanned in nearly a year! And yet this band is approximately one hundredth of the entire frequency range which should be scanned. A logical way out of this problem is therefore apparently to build scanning receivers which will look for a sinusoidal signal in a given broad frequency band. Once a signal of this kind has been detected, one will proceed to determine its frequency and to separate it from the background. This receiver will probably speed up the search for sinusoidal signals.

It should be noted that the increase of range by the reduction of P_n, without substantial increase of the observation time τ, has by now reached a dead end. Another one or two orders of magnitude can be gained at a considerable cost, but never those tens of orders of magnitude which are required, as we shall see below, for the P/P_n ratio before true galactic communication can be established.

The ranges and the required transmitter powers for $\lambda = 10$ cm have been computed from the above equations, assuming $P_n = 10^{-21}$ watt, $n = 10$. We see from the table that in isotropic transmission and reception, the range is mainly increased by increasing the transmitter power. No further improvement in the sensitivity of the receiving equipment which can be conceivably achieved by the existing technological means will appreciably increase the range. For example, by reducing the noise to one degree (which is hardly attainable given the present-day engineering skills), we increase the range by less than one order of magnitude. We are therefore of the opinion that energy, and energy alone, is the main obstacle to be overcome by all civilizations on their way to establishing interstellar communication, since all the other factors (signal generation, transmission) do not involve fundamental difficulties of the same order. The table clearly shows what enormous power is required for communication with our nearest galactic neighbors, the Andromeda Nebula and the Magellanic Clouds.

Let us consider the question of intergallactic communication in some detail.

4. Conditions for the detection of artificial signals from other galaxies

Directional receiving antennas will obviously be used for this purpose. Consider the case of isotropic transmission ($D_2 = 1$). Let the size of the transmitting galaxy in light years be r_2; its angular size, as seen from a distance l, is r_2/l. A receiving antenna pattern of the same width is obviously required to ensure simultaneous reception from any star of this galaxy. This gives a directive gain of the order of $D_1 = 4\pi l^2/r_2$, and the required transmitter power is lowered proportionately. A directive gain $D_1 = 4 \cdot 10^3$ is required for signal reception from the Andromeda Nebula (angular size of some 3°). The diameter of the receiving reflector should be $\sim 20\lambda$, i.e., an ordinary-size dish in the $10 - 50$ cm region. An antenna with $D_1 = 5 \cdot 10^3$ is needed to receive signals from the Magellanic Clouds, whose angular size is nearly 10°. It is noteworthy (see table) that a constant isotropic transmitter power of $\sim 10^{26}$ watt is required to ensure reception of signals from Andromeda and from other galaxies of approximately the same size, although the distances differ by a factor of fifty thousands. Hence it follows that with lobe widths covering a given area

TABLE

Interstellar and intergalactic communication range at $\lambda = 10$ cm as a function of transmitter power, antenna parameters, and the angular size of the transmitting and the receiving objects. A sinusoidal signal is assumed, exceeding 10-fold the set noise $P_n \approx 10^{-21}$ watt

No.	Transmission and reception site	Size r_2 of transmitting galaxy, covered by the antenna pattern (light years)	Distance to Earth l, in light years	Power, in watts, for isotropic transmission and reception	Power for isotropic transmission and directional reception		Power for directional transmission and reception		Power for directional transmission and reception with $D_1=D_2=10^8$ $\Delta\varphi_1=\Delta\varphi_2 \geq 1$
					$D_1=10^6$ $\Delta\varphi_1=10^1$ $D_2=1$	$D_2=1$; $\Delta\varphi_1$ is the angular size of the observed galaxy. $\Delta\varphi_1=(r_2/l)$	$D_1=D_2=10^5$	$\Delta\varphi_2$ is the angular size of the Galaxy (R_1,l)	
1	α Centauri		4	$2\cdot10^{17}$	$2\cdot10^{11}$		$2\cdot10^5$		120
2	The ten nearest stars		10	$1.6\cdot10^{18}$	$1.6\cdot10^{12}$		$1.6\cdot10^6$		160
3	A hundred nearest stars		20	$6\cdot10^{18}$	$6\cdot10^{12}$		$6\cdot10^6$		$6\cdot10^3$
4	Stars		100	$1.6\cdot10^{20}$	$1.6\cdot10^{14}$		$1.6\cdot10^8$		$16\cdot10^4$
5	Stars		1,000	$1.6\cdot10^{22}$	$1.6\cdot10^{16}$		$1.6\cdot10^{11}$		$16\cdot10^6$
6	Large Magellanic Cloud	$13\cdot10^3$	85,000	10^{26}	10^{20}	$2\cdot10^{23}(D_1=500)$		$2\cdot10^{22}(D_2=10)$	
7	Andromeda Nebula	$100\cdot10^3$	$2,10^6$	$6\cdot10^{28}$	$6\cdot10^{22}$	$1.5\cdot10^{25}(D_1=4\cdot10^3)$		$4\cdot10^{22}(D_2=4\cdot10^3)$	
8	Andromeda-type galaxies	$100\cdot10^3$	10^8	$1.6\cdot10^{32}$	$1.6\cdot10^{26}$	$1.6\cdot10^{25}(D_2=10^7)$		$1.6\cdot10^{17}(D_3=10^7)$	
9	The visible boundary of the Universe		10^{10}	$1.6\cdot10^{36}$					

68

of the galaxy, the transmitter power is independent of distance! This is
easily understood since the effective surface of the receiving antenna is
a function of the square of the distance. Indeed, putting D_1 $4\pi l^2/r_2$ in (1),
we find that the power required for isotropic transmission depends only
on the size-to-wavelength ratio of the transmitting galaxy:

$$\frac{P}{nP_n} = 4\pi 10^{32}\frac{r_2^2}{\lambda^2},$$

(4)

where r_2 is in light years.

For mutually directional communication between galaxies, the directive
gain of the transmitting antenna $D_2 = 4\pi l^2/r_1^2$, where r_1 is the size of the
receiving galaxy. Inserting the expressions for D_1 and D_2 in (1), we find

$$\frac{P}{nP_n} = \frac{10^{32}}{4\pi}\cdot\frac{r_2^2}{\lambda^2}\cdot\frac{r_1^2}{l^2}.$$

(5)

We thus arrive at an even more paradoxical conclusion: the larger the
distance between galaxies of given size, the smaller the transmitter power
required! This is of course true so long as the antenna surface, and hence
the directive gain, vary with the angular size of the galaxies, i.e., so
long as the transmitting and receiving antenna surfaces are proportional
to l^2.

The data listed in the table show that enormous power is required for
interstellar and intergalactic communications, and it is by no means clear
how this power can be generated by civilizations on the Earth level. If
we are to be guided by the Earth precedent, the interest in communication
with other worlds is aroused fairly early, before the essential material
means become available. It is quite probable that other civilizations,
having analyzed the situation, will also reach the conclusion that, while
incapable of "calling all the Universe", they can try to communicate
with their nearest neighbors.

Evolution is a slow process, and civilizations can be hardly expected
to wait patiently for some indefinite time in the distant future when they
are in a position to transmit to the entire Universe or to receive signals
from all the remote corners of the cosmos. Intelligent beings will probably
start probing their immediate neighborhood long before they are capable
of communicating on the intergalactic scale. We should therefore start
searching for intelligent signals from the nearest stars, within a radius
of a few hundreds of light years from the Earth. There are some 40 stars
within a radius of 15 light years from the Sun. If we assume the same
stellar population density for extrapolation to greater distances, we see
that within a sphere of 150 light years around the Sun there are $4\cdot10^4$ stars
and within a sphere with a radius of 1000 light years, more than 10^7 stars.
The last columns of the table show that the transmitter power required for
radio communication over distances of some 10^3 light years, using
directional transmitting and receiving systems, is well within our ability.

At this stage, we should apparently start looking for signals from our
immediate neighbors, always keeping in mind the vanishingly small
probability of encountering another civilizations just like ours in the
vicinity of the Sun. This probability, however, though small, is definitely

finite. If the probability that life should develop near any star is of the order of 10^{-7} /6/, then one other civilization should exist within a radius of 1000 light years!

The probability calculations, however, do not prove anything: what we need is an actual, experimental detection of intelligent signals. It should be noted that this detection is not an episodic occurrence: regular periodic scanning of the radio spectrum of the nearby stars should be instituted. The volume, nature, and duration of this project is entirely analogous to, say, the work involved in compiling a catalog of proper stellar motions or spectra of stars of a given magnitude, which requires cooperative effort of astronomers all over the world.

We now consider some particular problems concerning communication in the vicinity of the Sun.

5. Communication in the vicinity of the Sun

We assume that directional antennas are used both for transmission and reception. The antenna beam should obviously scan a certain angular area around the star over which planets may occur. What is the actual size of this area? Earth-like life can apparently evolve if the quantity of energy received from the primary is sufficient for sustaining various life processes. The same figure as for the Earth can be assumed, i.e., $s = 2\,cal/cm^2 \cdot min$. If L is the energy emitted by the star, we have $r_{1,2}^2 = L_{1,2}/\pi s\ 10^{32}$. Most of the nearby stars radiate $10^{-2} - 10^{-3}$ of the energy emitted by the Sun. The "life radius" $r_{1,2}/2$ of these stars is therefore smaller by one order of magnitude than that of the Sun. The angular size of the Mars orbit as viewed from a distance $l = 10$ light years is about $0''.5$.

The sensitivity of this narrow-beam reception, however, may suffer due to interference from the radio emission of the primary. In case of the solar system, for example, with the beam area covering the Earth's orbit, the angular size of the Sun occupies $1/200$ of the angular size of the antenna pattern. The resulting antenna noise temperature is $\sim T_\odot/2 \cdot 10^5$, i.e., nearly $2\,°K$ at decimeter wavelengths.

With other stars, the directive gain of the antennas can apparently be raised by one order of magnitude. Here the antenna size becomes limited by engineering considerations. To ensure a beam width of $1''$, antennas with a diameter $d = 10^5\lambda$ are required, i.e., $d = 10\,km$ for $\lambda = 0.1\,m$. We do not know yet how such antennas are to be built. The most we can hope for at present are antennas with $d = 30\text{-}100\,m$ for wavelengths $\lambda = 3\,cm$ and longer. This gives a beam width of from $4'$ ($\lambda = 3\,cm$) to $12'$ ($\lambda = 30\,cm$), and correspondingly $D \sim 10^6$. The table lists the power and the antenna size required for communication with the nearest stars, assuming the now attainable directive gain of 10^6 and the directive gain of antennas which will be built in the near future, 10^8. We see from the table that the transmitter power corresponding to the given antenna sizes is quite small.

The existing antennas require a fairly high transmitter power, which is nevertheless attainable, at least for transmission over a range of $10 - 20$ light years.

Let us now summarize the situation and try to draw some conclusions.

Radio engineering has reached a stage when we can intelligently discuss the question of systematic search for artificial electromagnetic signals from space in the range of centimeter and decimeter wavelengths.

The most probable form of artificial signals is apparently that which permits sharp differentiation from the natural radiations. Among these distinctive signals preference should be given to monochromatic signals with a very narrow line width (as those emitted by modern molecular and quantum generators).

The search for monochromatic radio lines should be made in the continuous spectrum of centimeter and decimeter waves. It is also advisable to survey the neighborhood of the radio lines of various molecules used in molecular generators and amplifiers (the 1.25 cm ammonia line, the 0.4 cm formaldehyde line).

It is apparently also advisable to institute a search for radio lines in the centimeter and decimeter wavelengths in the spectra of the nearest galaxies, the Andromeda Nebula and the Magellanic Clouds, with a view to detecting type II civilizations. A call signal should be periodically transmitted from the Earth to the nearest stars, the transmitter power being sufficient for the detection of this signal by the same means as those currently in use on Earth. This requires transmitter power of a few hundreds of kilowatts at centimeter wavelengths with the existing antennas.

Signals can be sent to the nearest stars without tying up many transmitters: a few tens of the nearest stars can be "illuminated" periodically in succession. An optimal transmission program should of course be developed. Another useful project is to patrol several stars with radio receivers for a certain time.

However, the probability of detecting intelligent signals from the nearest stars will remain vanishingly small unless we proceed with a regular survey of some ten million stars within a radius of 1000 light years from the Earth — the ultimate radio range for Earth-type civilizations. The entire problem of interstellar communications can only be solved by international cooperation and coordination, and it may take a very long time.

We are witnessing the first rudiments of an experimental approach to the problem of the existence of other civilizations in the Universe. The solution of this problem requires comprehensive investigations on a very large scale, calling for the concerted effort of scientists working in different branches of science. This problem is obviously of great theoretical and practical importance, and we therefore suggest that a special committee be set up by the Council of Radio Astronomy and the Astronomical Council to deal specifically with the scientific aspects of the problem and coordination of research projects.

Bibliography

1. Cocconi, G. and P. Morrison. — Nature, **184** : 844. 1959.

2. Dyson, F. J. — Science, **131** : 27. 1960.

3. Kardashov, N. S. — Astronomicheskii Zhurnal, **41** : 282. 1960

4. Troitskii, V. S. — JETP, **34** : 390. 1958.

5. Troitskii, V. S. and V. V. Khrulev. — Radiotekhnika i Elektronika, 1 : 831. 1956.

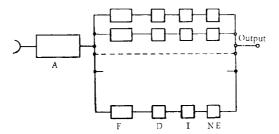6. Cameron, A. G. W. — Interstellar Communication. New York. 1963.

RADIO COMMUNICATION
WITH EXTRATERRESTRIAL CIVLIZATIONS

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The aim of this paper is to consider the possibilities of communication with extraterrestrial civilizations (whose technology is an outgrowth of scientific principles that are already established on the Earth and which lead the Earth civilization by a few decades. The Earth technology is assumed on the present-day level. Although some civilizations are probably more advanced than we are by thousands or even millions of years, our restricted approach is apparently not unreasonable. This paper does not pretend to completeness: it only discusses some particular examples, which are not meant as illustrations of optimal cases.

Let us consider the transmission of signals in the form of long monochromatic trains of pulses. This technique is no less noiseproof than other methods of transmission, and yet it is simpler to achieve; therefore it will probably be adopted in the beginning by young civilizations for purposes of interstellar communication. The signal frequency is of course not known in advance, and it may change when information is being transmitted. In this case, the optimal receiver will have a circuitry like that block-diagrammed in the figure.

Here A is the amplifier, which may include a frequency changer; F filters with a band Δf overlapping the entire frequency range; D detectors; I integrators which recover the energy passing through the filter during the integration time τ; NE suitable nonlinear elements whose outputs are added. A signal is registered when the output of this receiver exceeds a certain value.

For simplicity, without sacrificing much of the noiseproof properties of the receiver, the nonlinear elements can be replaced with threshold

devices which produce an output signal only if the oscillatory energy passing through the filter in the time τ has exceeded a certain threshold value. It is this particular receiver scheme that is considered in what follows.

Let the transmitting and the receiving antennas with effective surfaces S_1 and S_2 be pointed at one another. The maximum reception range is then given by

$$R = \sqrt{\frac{PS_1 S_2 \tau}{\lambda^2 k T_n \Psi}} , \tag{A}$$

where P is the transmitter power, λ the wavelength, $k = 1.38 \cdot 10^{-23}\,\mathrm{J/deg}$, T_n receiver noise temperature; Ψ is a function of Δf, the number of filters n, and threshold setting, which depends on the probability of false response p_{fr} and the permissible probability of signal loss by the receiver, p_{sl}. When considered as a function of Δf, Ψ has a minimum for $\Delta f \approx 1/\tau$. For p_{fr} and p_{sl} less than 10^{-2}, it is given by

$$\Psi_m \sim \left(\sqrt{\ln \frac{n}{p_{fr}} - 2} + \sqrt{\ln \frac{1}{p_{sl}} - 2} \right)^2 .$$

In some cases, when τ is large, Δf cannot be made equal to $1/\tau$, since due to the intrinsic frequency drift the signal will miss the narrow passband of the filter. With $\Delta f \gg 1/\tau$, we have

$$\Psi \cong \sqrt{2 \Psi_m \tau \Delta f} .$$

It is undesirable to have $\Delta f < 1/\tau$, since this will complicate the design and increase Ψ, i.e., reduce R.

We now consider a particular example. Let the transmitter power commanded by an extraterrestrial civilization be $P = 10^9$ watt (1% of the electric power requirements of the USA). The effective surface of the transmitting antenna is

$$S_1 = 10^5\,\mathrm{m}^2.$$

and the effective surface of our receiving antenna is

$$S_2 = 10^4\,\mathrm{m}^2.$$

Set noise

$$T_n = 30°.$$

Receiving antennas with these parameters can be built without much difficulty.

Transmission wavelength

$$\lambda = 0.1\,\mathrm{m}.$$

For a frequency drift of 10^{-10} (which is readily attainable at present), we obtain for the filter passband

$$\Delta f = 0.3 \, c/s.$$

With this passband we may take $\tau \gg \Delta f$. Putting $\tau = 1800$ sec, $p_{fr} = p_{sl} = 10^{-5}$ and $n = 10^9$, we find

$$\Psi = 280.$$

From relation (A) we then have

$$R = 1.28 \cdot 10^{21} \, m$$

or 128,000 light years, which is more than the diameter of the Galaxy.

If information is sent through this line, and the signal frequency is changed from transmission to transmission, the information rate is

$$\frac{\lg_2 n}{\tau} = \frac{\lg_2 10^9}{1800} = 1/60 \text{ bits per sec.}$$

The information rate rapidly increases as τ decreases. If we put $\tau = \Delta f^{-1} = 3.3$ sec, and $p_{fr} = p_{sl} = 10^{-5}$, $n = 10^9$ as before, we find $\Psi = 73$ and $R = 10^{20}$ m, or 10,000 light years. The corresponding information rate is

$$\frac{\lg_2 n}{\tau} = \frac{\lg_2 10^9}{3.3} = 9 \text{ bits per sec.}$$

For distances of 100 light years, τ can be reduced by four orders of magnitude, and the information rate will approximately increase to the same extent.

The receiver being considered is provided with fairly narrow-band filters. The transmitter and the receiver both accelerate and decelerate due to the motion of the home planets in space, and this obviously changes the frequency of the signal. These frequency changes must be compensated on location, since otherwise the signal may miss the filter's narrow passband. The compensation can be readily introduced since the acceleration of planetary motion is known at each point.

The very large number of separate channels in the receiver (see figure) can be apparently replaced with a simpler device performing the same function.

How are we going to find a star with a powerful transmitter located on one of its planets?

Suppose that the transmitting civilization has built a transmitter with the parameters from the previous example, i.e., $P = 10^9$ W, $S_1 = 10^5$ m^2, $\lambda = 0.1$ m. The antenna is pointed alternatively at different stars or is allowed to scan the entire celestial sphere, drifting across a single star in, say, $\tau = 3$ sec. For large τ, the problem is even simpler.

The antenna beam fills a solid angle $\dfrac{\lambda^2}{S_1}$, and it therefore scans the entire celestial sphere in the time

$$\tau_r = \tau \frac{4\pi S_1}{\lambda^2}.$$

74

For the above numerical parameters, we find $\tau_r = 3.8 \cdot 10^8$ sec or 12 years.

A considerably shorter time is obtained if the antenna is pointed at a certain star and then rapidly switched to another star, etc. The scanning time for all the 10^7 stars within the radius of 1000 light years is

$$\tau_r = 3 \cdot 10^7 \, \text{sec, or 1 year.}$$

If we assume that a preliminary selection of the most "promising" stars reduces the population to 1% of the total ten millions, the scanning time drops to $\tau_r = 3 \cdot 10^5$ sec, or some four days. The scanning time decreases proportionately for stellar populations within spheres of smaller radii. The technique of rapid antenna switching from one star to another thus reduces the scanning time to a reasonable level.

Let the receiving system be an array of beamed antennas covering the entire celestial sphere. In this case, a transmitter with the above parameters can be detected at a distance of 1000 light years if the receiving antenna surface, according to equation (A), is $S_2 = 100 \, \text{m}^2$. It is assumed that the receiver functions as indicated in the figure and that $\Delta f = \tau^{-1}$, $T_n = 30°$. Seeing that the beam of this antenna occupies a solid angle λ^2/S_2, we find that

$$m_2 = \frac{4\pi S_2}{\lambda^2} = 1.2 \cdot 10^5 \text{ beams}$$

are required to cover the entire celestial sphere.

In this arrangement, the antenna is not expected to track the star. Each antenna may therefore have as many as ten beams. The number of individual antennas may therefore be substantially less than m_2. The number of receiving channels, however, must be exactly m_2, and each receiving channel should be equipped with filters overlapping the entire relevant frequency band.

If we assume that the transmitting civilization is sufficiently advanced and its astronomers can actually select the 1% of stars which in principle may support Earth-type civilizations, the scanning of all the selected stars within a sphere of 1000 light years radius will take about four days.

The entire celestial sphere need not be scanned at one time: different areas of the sky, say, those having different declinations, can be scanned at different times. Thus, if the sky is divided into 10 areas, the survey of each area can be completed in, say, one month (the signal, if any, will be detected 7 times during this period), and the entire celestial sphere will be scanned in approximately one year. The number of receiving channels and antennas can be further reduced by one order of magnitude.

The above receiving network, though by no means cheap or easy to build, can be erected on Earth. This system will detect extraterrestrial civilizations which have transmitters with the above parameters and are located within the radius of 1000 light years from the Earth. Since there are nearly 10^7 stars within this sphere, the search will be successful if at least one of the ten million stars has a transmitter of the required kind.

If the distance scale is reduced, the search becomes progressively simpler.

The table below lists some data for spheres with radius of 2000, 1000, 500, and 200 light years with 10^8, 10^7, 10^6, and 10^5 stars, respectively. The data of the table have been derived along the lines indicated above. Column 7 gives the number of areas to be scanned separately if the survey of the entire celestial sphere is to be completed in one year. The scanning time for each area was assumed approximately 10 times greater than the figure given in column 4.

We see from the table that if there is a single Earth-type civilization in 10^8 stars, its detection at the present stage of our technological development is nearly impossible; if there is a single civilization in 10^7 stars, it can be detected with some effort; if there is one civilization in 10^6 stars, its detection by the available means is quite probable.

Radius, light years	Number of stars	Time to scan all the stars	Time to scan 1% of the stars	Receiving antenna surface, m²	Number of receiving channels to cover the entire sky	Number of survey areas	Number of receiving channels with survey areas
2000	10^8	10 years	36 days	400 m²	480,000	1	480,000
1000	10^7	1 year	4 days	100 m²	120,000	10	12,000
500	10^6	36 days	9 hrs	25 m²	30,000	100	300
200	10^5	4 days	1 hr	4 m²	4,800	1000	5

If the extraterrestrial civilization commands more powerful resources, we can of course detect it from considerably greater distances.

Once the existence of a civilization has been established, a large antenna should be pointed in the corresponding direction, since besides the powerful call signals intended for detection by other civilizations, it probably transmits information, meaningful messages that can be picked up with high-efficiency antennas only. To establish a bilateral communication, we should send a radio message to the discovered civilization. Our signal will be picked up without any difficulty, since our transmitter can be pointed precisely in the direction of the extraterrestrial civilization that we have previously discovered. After this preliminary exchange of messages, the antennas of the two civilizations will be pointed at one another and a more effective exchange of information will be established.

In conclusion let us consider the possibility of detecting a civilization even though it does not transmit special "detection" signals. The power of the radio transmitters used for internal purposes by these civilizations is probably of the order of tens of kilowatts, and the antennas in common use have a directive gain $g_1 = \dfrac{4\pi S_1}{\lambda^2}$ (the probability of picking up narrower antenna beams is too small). The receiver passband, as before, is 0.3 c/s. A narrower passband is inadvisable, since the Doppler frequency shift will not be compensated on the transmitting side. For the same reason we take $\tau = 3$ sec, $P = 10^5$ watt, $\dfrac{S_1}{\lambda} = 10$, $S_2 = 10^5$, $\Psi = 70$, $T_n = 30$. From equation (A),

we find

$$R = 3 \cdot 10^{15} \, \mathrm{m}, \ \text{or } 0.3 \text{ light years.}$$

We see that even the civilizations occupying the nearest stars cannot be detected unless they send special signals or radiate (for some obscure reason) exceptionally high power.

CONCLUSIONS

If a civilization does not send special "detection" signals, it apparently cannot be detected even by its nearest stellar neighbors.

If a civilization somewhat more advanced than we (approximately by a few decades) sends special radio signals, we can detect these signals from distances of 500 — 1000 light years.

Once civilizations have detected one another, they can establish radio communication on the galactic scale.

SOME ASPECTS OF THE SEARCH FOR RADIO SIGNALS FROM OTHER CIVILIZATIONS AND THEIR ANALYSIS

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In this paper we consider some aspects of the search for radio signals from extraterrestrial civilizations and their analysis in the light of the basic premises of the information theory.

It should be remembered that the frequency of the expected radio signals, as well as the direction of the source, the form, and the statistical structure of the signal are all unknown. On the other hand, we are obviously interested in detecting these signals, if any, in the shortest possible time. To solve this problem, we should first establish quantitative relations between the probable search time and all the other parameters of the signal. In particular, we should relate the search time to the distances between civilizations. We give here some quantitative relations, as well as some qualitative considerations on the search and the analysis of incoming radio waves.

A thing to remember is that the minimum quantity of information required to identify the artificial signals with sufficiently high probability is comparatively small. It is apparently no more than a few bits or tens of bits, as far as call signals are concerned. Our aim is thus to find reception techniques ensuring transmission of this minimum information in a minimum time. In particular, we should consider the question of the receiver frequency band and the advantages of directional reception and transmission.

Let us first consider the frequency search for artificial signals. For a given transmitter power of civilization A, the power flux density picked up by civilization B varies as $\frac{a}{R^2}$, where R is the distance between the two civilizations. The fluctuational noise power increases in proportion to the receiver frequency band, so that to obtain a sufficiently strong effective signal above the noise level the receiver band should be chosen as

$$\Delta f = \frac{b}{R^2} \tag{1}$$

Let $\Delta_0 f$ be the total frequency band to be searched. We furthermore assume that a search receiver is used with automatic retuning and intermediate-frequency narrow-band filters of passband Δf. To avoid reduction

of the effective signal at the filter output by transients, the variable
frequency should go through the band Δf in a time of the order of

$$\tau \approx \frac{c}{\Delta f},$$

where c is a coefficient of the order of unity. The total time for the
variable tuning frequency to run over the entire frequency range $\Delta_0 f$ is thus

$$\tau_f = n\tau = \frac{\Delta_0 f}{\Delta f} \cdot \frac{c}{\Delta f},$$

where n is the number of filter bands Δf covering the entire frequency
band $\Delta_0 f$.

Inserting expression (1) for Δf, we find

$$\tau_f = \frac{c \Delta_0 f}{\left(\frac{b}{R^2}\right)^2} = \frac{c}{b^2} (\Delta_0 f) R^4. \tag{2}$$

i.e., with this particular technique using a single-channel search receiver,
the total search time is directly proportional to the entire frequency band
$\Delta_0 f$ to be searched and the fourth power of the distance between the
civilizations.

This highly unfavorable variation of the search time with distance
indicates that the application of a single-channel search receiver in our
case is unadvisable. Multichannel receivers should be used, searching
simultaneously a broad range of frequencies. If the receiver is equipped
with n band filters, the search time is proportional to the square of the
distance between the civilizations, i.e.,

$$\tau_f = k_0 R^2, \tag{3}$$

where k_0 is a proportionality coefficient. The complexity of the equipment,
however, increases in proportion to R^2, but this approach should never-
theless be preferred since band filters are simple and cheap elements.

The frequency band to be searched should be chosen proceeding from
the frequency distribution of the effective noise temperature of the radio
background. We should concentrate on frequencies corresponding to
minimum noise. Spectral regions near the second, third, and higher
harmonics of the 21-cm wavelength (the emission line of neutral hydrogen)
should also be surveyed.

Let us now consider some aspects of direction search. We shall also
evaluate the relative merits of search systems using directional and
isotropic antennas.

Let P be the radio power radiated by an extraterrestrial civilization.
Let P_s and P_n be the power of the received signal and of noise at the
reception site, respectively. For weak signals,

$$\frac{P_s}{P_n} \ll 1.$$

According to Shannon's theorem the maximum rate of information transmission by an isotropic transmitter is given by

$$C = \Delta f \lg_2\left(1 + \frac{P_s}{P_n}\right) = \frac{\Delta f}{\ln 2}\ln\left(1 + \frac{P_s}{P_n}\right) \approx \frac{(\Delta f)\,P_s}{(\ln 2)P_n}.$$

Putting

$$P_n = P_{n\,sp}\Delta f.$$

where $P_{n\,sp}$ is the specific noise power per unit frequency band, we obtain

$$C = \frac{P_s}{(\ln 2)\,P_{n\,sp}}. \tag{4}$$

The quantity of information transmitted in time T is

$$Q = CT. \tag{5}$$

Substituting (4) in (5), we find

$$Q = \frac{P_s\,T}{(\ln 2)P_{n\,sp}} \tag{6}$$

or

$$T = \frac{(\ln 2)\,QP_{n\,sp}}{P_s}. \tag{7}$$

From (7) it follows that for very weak signals at the receiving site, the time T for the reception of the minimum quantity of information Q is proportional to this Q and to the ratio of the specific noise power to signal power; it is furthermore independent of the frequency band Δf.

Now, suppose that the extraterrestrial civilization transmits with a directional "pencil-beam" antenna. We assume that the pencil beam scans the entire surface of a sphere of radius R, having the area

$$S = 4\pi R^2.$$

Let N be the number of times the pencil beam area goes into the spherical surface (i.e., the number of partial areas each equal to the trace of the beam on the sphere). We now calculate the quantity of information that can be transmitted with the pencil beam in the same time T as in the isotropic transmission.

The power flux increases by a factor of N due to the directive gain, but the time required to "illuminate" each of the N partial areas is now $\frac{T}{N}$. The total quantity of information at the receiving site is, according to (6),

$$Q' = \frac{(NP_s)\,\dfrac{T}{N}}{(\ln 2)\,P_{n\,sp}} = \frac{P_s T}{(\ln 2)\,P_{n\,sp}}. \tag{8}$$

Comparison of (8) and (6) shows that

$$Q' = Q,$$

i.e., by switching from isotropic to directional transmission, we did not change the quantity of information transmitted by weak signals during a given time T.

For strong signals,

$$\frac{P_s}{P_n} > 1,$$

the quantity of information sent by an isotropic transmitter during the time T is

$$Q = CT = T\Delta f \lg_2\left(1 + \frac{P_s}{P_n}\right). \tag{9}$$

and in directional transmission

$$Q' = \frac{T}{N} \Delta f \lg_2\left(1 + \frac{NP_s}{P_n}\right). \tag{10}$$

Comparison of (9) and (10) gives

$$Q' < Q, \tag{11}$$

i.e., if the location of the receiver is unknown, the quantity of transmitted information is decreased by switching from isotropic to beamed transmission, all other conditions remaining equal. In other words, under the above conditions, the time required to establish contact between civilizations is greater for beamed transmitters than for isotropic ones.

This paradoxical conclusion applies only if the transmitting civilization uniformly scans all the possible directions in space. If, however, the signals are sent only in some selected directions, where the probability of finding intelligent life is comparatively high, the situation becomes radically different.

Let the ratio of the surface area of the entire sphere of radius R to the selected search area be M. Then, from (10), the quantity of information Q'' that can be transmitted in time T by a beamed antenna is

$$Q'' = \frac{MT}{N} \Delta f \lg_2\left(1 + \frac{NP_s}{P_n}\right). \tag{12}$$

The application of beamed antennas is advantageous only if

$$Q'' > Q, \tag{13}$$

where Q is expressed by (9). Condition (13) can be written in the form

$$\frac{M}{N} \lg_2\left(1 + \frac{NP_s}{P_n}\right) > \lg_2\left(1 + \frac{P_s}{P_n}\right).$$

81

Putting

$$\frac{P_s}{P_n} = m$$

and changing over to natural logarithms, we find

$$\frac{M}{N} \ln(1 + mN) > \ln(1 + m). \qquad (14)$$

If the received signals are very weak, we have

$$m \ll 1$$

and condition (14) is written as

$$\frac{M}{N} \ln(1 + mN) > m \qquad (15)$$

or

$$M > \frac{mN}{\ln(1 + mN)}. \qquad (16)$$

Putting in (16), say, $m = 0.1$ and $N = 10^7$, we find

$$M > 7.25 \cdot 10^4. \qquad (17)$$

In our example, beamed transmission is more advantageous only if the search area constitutes less than 1/70,000th of the celestial sphere. Otherwise, isotropic transmission should be preferred. Thus, if only a small fraction of the stellar population in a sphere of a given radius need be scanned, the search for extraterrestrial civilizations can be made with beamed antennas.

The search for radio signals from extraterrestrial civilizations should be supplemented with an analysis of the statistical structure of the signals. In particular, if narrow-band signals are received, it is advisable to determine experimentally the two-dimensional probability density distribution of the points on a plane spanned by the tip of the vector which represents the amplitude and the phase of the incoming oscillations. The nature of the surfaces mapping these two-dimensional densities is indicatory, say, of whether or not the oscillations are generated by feedback oscillators. It is our opinion that analysis of the statistical structure of the incoming signals should prove useful in deciding what signals are "artificial" and what are the product of natural processes unrelated to the activities of intelligent beings.

The analysis of radio signals from space should not be restricted to the effects of additive background noise only: we must take account of multiplicative noise and distortions due to random variations in the parameters of the propagating medium, as well as systematic variations introduced by the Doppler effect and other factors.

1. The search for radio signals from extraterrestrial civilizations should be made using multichannel radio receivers with a large number of narrow-band filters, with passbands of the order of a few c/s or tenths of c/s.

2. The astronomers should select the most probable celestial objects as regards the existence of alien civilizations, and narrow-beam antennas should be pointed at these objects. The application of beamed antennas is advantageous only if the ratio of the search area to the total area of the celestial sphere is very small. The criterion for the applicability of beamed antennas is expressed mathematically by inequality (13).

3. The search for radio signals from extraterrestrial civilizations should be accompanied by an analysis of the statistical structure of the incoming radiation and, in particular, of the two-dimensional probability density distribution of the points on the plane traced by the tip of the vector which represents the amplitude and the phase of the received oscillations.

THE INFLUENCE OF THE SPACE ENVIRONMENT AND OF THE EARTH'S ATMOSPHERE ON THE APPARENT ANGULAR SIZE OF RADIO SOURCES

N. A. SMIRNOVA and N. L. KAIDANOVSKII

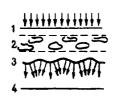Main Astronomical Observatory, USSR Academy of Sciences, Pulkovo

An artificial radio source is of necessity a point source. A point source, however, may be broadened into an apparently extended source because of the scattering of radio waves by inhomogeneities in the interstellar space and in the Earth's atmosphere.

If the beam path S is interspersed with numerous inhomogeneities whose mean size r is considerably greater than the wavelength λ, the mean square deviation of the signal phase from the unperturbed value is /1/

$$\overline{\varphi^2} = \frac{4\pi^{\gamma_2} Sr}{\lambda^2} \overline{\Delta n^2}, \tag{1}$$

where $\overline{\Delta n^2}$ is the mean square fluctuation of the refractive index; we take $\sqrt{\overline{\Delta n^2}} \ll 1$.

If $\overline{\varphi^2} \ll 1$, the scattered wave carries off a vanishingly small fraction of signal power, and scattering is therefore ignored. A point source is extended only if the wave front is highly agitated ($\overline{\varphi^2} \gg 1$). Making use of data on the inhomogeneity of the troposphere /2, 3/, ionosphere /4, 5/, interplanetary /6, 7, 8, 9/ and interstellar /10, 11/ space, and the metagalaxy /10, 12/ and computing the $\overline{\Delta n^2}$ of an ionized medium from the variation of electron concentration $\sqrt{\overline{\Delta N^2}}$, we can find the mean square phase deviation from relation (1). The calculated values of $\overline{\varphi^2}/\lambda^2$ and the parameters of the medium are listed in Table 1.* We see from the table that the largest phase perturbations are acquired by the wave while propagating in the interstellar and the interplanetary space. Tropospheric scattering is high only at millimeter wavelengths, while perturbations produced by agitated ionosphere are substantial for wavelengths above 50 cm only. Wave front distortion in an inhomogeneous layer is schematically illustrated in the figure.

Wave front distortion in an inhomogeneous layer:

1) plane wave front;
2) inhomogeneous layer;
3) distorted wave front;
4) ground.

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* The effect of clouds and hydrometeors in the troposphere is ignored, since an observer on the lookout for point sources can afford to schedule his observations for ideal weather conditions. The ground atmospheric layer, which limits the resolution of earthbound radio telescopes to values not exceeding $\theta \approx 2.5 \cdot 10^{-5}/\lambda$, is also disregarded, since in principle radio telescopes can be built without channels passing in the ground layer.

The earthbound observer is affected by the inhomogeneities of inter-stellar and interplanetary space, as well as by the inhomogeneities of the agitated atmosphere. Applying the geometrical-optics approximation, we obtain the following expression for the mean square deviation of the ray from the unperturbed direction:

$$\overline{\sigma_i^2} = 4\pi^{\,\prime\prime}\,\frac{S}{r}\,\overline{\Delta n^2}. \tag{2}$$

The ray may reach the observation point at any angle between the limits $\pm\,\sigma = \pm\sqrt{\overline{\sigma_i^2}}$. If the angle σ is much less than the angular size of the inhomogeneity $a \sim \dfrac{r}{S}$, the radio waves strike an antenna with a diameter $D \ll r$ in a nearly parallel beam after having penetrated through a layer with a thickness much less than the correlation radius r. The point source is thus displaced without revealing any noticeable increase in angular size. Moving inhomogeneities produce position fluctuations, resulting in source "pulsation" with a period $t = \dfrac{r}{v}$, where v is the velocity of the refractional inhomogeneities.

If now $\sigma \gg a$, the deflections of the individual rays are uncorrelated, the initially parallel bunch diverges, and the observer sees an extended source of the angular size σ.

TABLE 1

Medium	Tropo-sphere	Ionosphere		Interplanetary medium		Interstellar medium		Meta-galaxy
		calm	agitated	ecliptic plane*	ecliptic pole	galactic plane	galactic pole	
S, cm	10^6	$4\cdot10^7$	$4\cdot10^7$	10^{14}	$0.5\cdot10^{13}$	$6\cdot10^{22}$	$6\cdot10^{20}$	10^{28}
r, cm	$6\cdot10^3$	$2\cdot10^4$	10^6	10^9	10^9	$3\cdot10^{18}$	$3\cdot10^{18}$	10^{22}
$\bar{N}$, cm^{-3}	—	10^4	10^4	10^2	20	1	1	10^{-5}
$\sqrt{\overline{\Delta N^2}}$, cm^{-3}	—	10^2	10^4	10^2	20	1	1	10^{-5}
$\overline{\Delta n^2}/\lambda^4$	10^{-12}	$2\cdot10^{-23}$	$2\cdot10^{-19}$	$2\cdot10^{-23}$	$0.8\cdot10^{-24}$	$2\cdot10^{-27}$	$2\cdot10^{-27}$	$2\cdot10^{-37}$
$\overline{\varphi^2}$, rad$^2/\lambda^2$	$0.42/\lambda^4$	$1.1\cdot10^{-9}$	$5\cdot10^{-4}$	$1.4\cdot10^2$	0.28	$2.5\cdot10^{16}$	$2.5\cdot10^{14}$	$18\cdot10^{15}$

* In sunward observations.

The ultimate resolution of radio telescopes intended for source diameter measurements is thus limited by the scattering angle $\theta \gg \sigma$ in the range of wavelengths where $\sigma > a$. For wavelengths where $\sigma \ll a$ when sources appear to pulsate without lateral spread, the resolution of aperture-filled and multiunit antenna arrays of diameter D is limited by the condition $D \ll r$, i. e., $\theta \gg \dfrac{\lambda}{r}$. Source pulsation produces apparent spread of the source by an amount $\Delta\theta \simeq \dfrac{\sigma\tau}{t}$, where τ is the recording time ($\tau < t$). This may limit the ultimate resolution $\theta > \Delta\theta$ if for some reason the averaging time cannot

be made to satisfy the condition $\tau \ll \theta \dfrac{t}{\sigma}$. A two-unit interferometer may have a base $D > r$ if the diameter of each of the component antennas is $d \ll r$. In this case the effect of position fluctuation and dispersion on the apparent spread of the source can be virtually eliminated if the recording time constant $\tau' < \dfrac{t}{e\sqrt{\bar{\varphi}^2}}$, and the relative receiver band width $\dfrac{\Delta f}{f} < \dfrac{1}{\sqrt{\bar{\varphi}^2}}$.

Calculated values of α, σ/λ^2, and t are listed in Table 2.

TABLE 2

Medium	Tropo-sphere	Iono-sphere	Interplanetary medium		Interstellar medium		Meta-galaxy
			ecliptic plane	ecliptic pole	galactic plane	galactic pole	
α, rad	$6 \cdot 10^{-3}$	$2.5 \cdot 10^{-2}$	10^{-5}	$2 \cdot 10^{-4}$	$5 \cdot 10^{-5}$	$5 \cdot 10^{-3}$	10^{-6}
σ/λ^2	$3.5 \cdot 10^{-5}$	$7.5 \cdot 10^{-9}$	$4 \cdot 10^{-9}$	$2 \cdot 10^{-10}$	$2 \cdot 10^{-11}$	$2 \cdot 10^{-12}$	10^{-15}
t, sec	$3 - 5$	$25 - 50$	50	50	very large		

Analysis of the data in this table shows that for the troposphere, ionosphere, interstellar medium (in the direction of the galactic pole), and the metagalaxy, σ is substantially less than the angular size of the inhomogeneities at all the wavelengths which are used in radio astronomic observations, and the scattering by inhomogeneities in these media will only lead to position fluctuation. Interplanetary inhomogeneities, on the other hand, produce both refraction and lateral spread of the source. In observations in the ecliptic plane at wavelengths shorter than 16 cm, $\sigma \ll \alpha$ and only pulsation is observed. For $\lambda > 50$ cm, $\sigma > \alpha$ and the point source spreads to angular size $\sigma = 4 \cdot 10^{-9} \lambda^2$. In the intermediate region $16 < \lambda < 50$ cm, source pulsation and lateral spread register simultaneously. In observations in the direction of the ecliptic pole, no lateral spread is observed up to wavelengths of nearly 3 m, and at wavelengths shorter than 10 m a point source spreads to angular size $\sigma = 2 \cdot 10^{-10} \lambda^2$. The influence of the galactic medium on the apparent angular size of the radio source is felt only at decameter wavelengths.

<center>CONCLUSIONS</center>

1. When the receiver passband is fairly narrow (so as to prevent dispersion), the ultimate resolving power of filled-aperture and multiunit antenna arrays at wavelengths $\lambda > 50$ cm is limited by the condition $\theta > \lambda/r_n > \lambda \cdot 10^{-6}$, where r_n is the correlation radius of the inhomogeneities in the agitated ionosphere. For $16 < \lambda < 50$ cm, where apparent lateral spread of the source is produced by scattering by the interplanetary gas (in the plane of the ecliptic), $\theta > \sigma > 4 \cdot 10^{-9} \lambda^2$; in the range from 16 cm to millimeter wavelengths, $\theta > \lambda/r_{pl} > \lambda \cdot 10^{-6}$, where r_{pl} is the correlation

radius of inhomogeneities in the interplanetary medium. In the millimeter range ($\lambda < 0.2$ cm), $\theta > \lambda / r_{tr} > 2 \cdot 10^{-4} \lambda$, where r_{tr} is the correlation radius of tropospheric inhomogeneities. The peak resolution $\theta > \lambda \cdot 10^{-9}$ rad is thus attained in the centimeter region.

2. The ultimate resolving power of two-unit interferometers at $\lambda > 16$ cm (for observations in the plane of the ecliptic) and $\lambda > 300$ cm (for observations in the direction of the ecliptic pole) is limited by the lateral spread of the radio source due to scattering by the interplanetary medium; here $\theta > 4 \cdot 10^{-9} \lambda^2$ and $2 \cdot 10^{-10} \lambda^2$, respectively. For wavelengths shorter than 16 and 300 cm, respectively, the base of the two-unit interferometer is virtually unlimited, since with a relative bandwidth $\dfrac{\Delta f}{f} < \dfrac{1}{\sqrt{\bar{r}^2}}$, the apparent source spread by dispersion is $\delta < \theta = \dfrac{\lambda}{D}$.

In conclusion we note that the above estimates are highly tentative, since no sufficient experimental data are available on inhomogeneities in the interplanetary and interstellar space.

Erection of high-resolution radio telescopes will not only help in angular size measurements of radio sources, but will also provide more accurate data on the parameters of the ionosphere and the interplanetary space.

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Bibliography

1. Chandrasekhar, H.—Monthly Notices, **112**: 475. 1952.

2. Vysokovskii, D. M. Nekotorye voprosy dal'nego troposfernogo rasprostraneniya ul'trakorotkikh radiovoln (Some Problems of Long-Range Tropospheric Propagation of Ultrashort Radio Waves). — Izdatel'stvo AN SSSR. 1958.

3. Arenberg, A. G. Rasprostranenie detsimetrovykh i santimetrovykh voln (Propagation of Decimetric and Centimetric Waves). — Sovetskoe Radio. 1957.

4. Voprosy dal'nego rasprostraneniya UKV (Long-Range Propagation of Ultrashort Waves). — Svyaz'izdat. 1958.

5. Dreify i neodnorodnosti v ionosfere (Drifts and Inhomogeneities in the Ionosphere). — Izdatel'stvo AN SSSR. 1959.

6. Shklovskii, I. S. Fizika solnechnoi korony (Physics of the Solar Corona). — Fizmatgiz. 1962.

7. Blackwell, D. E.—Monthly Notices, **116**(1) 58. 1956.

8. Brandt, J. C. A model of the Interplanetary Medium. — Berkeley Astr. Depart. University of Calif. Icarus, **1**(1): 1. 1962.

9. Gringaus, K. J.—Intern. Conven. (Brit. IRE) on Radio Techniques and Space Res., 5—9, July. 1961.

10. Ginzburg, V. L. and S. I. Syrovatskii. Proiskhozhdenie kosmicheskikh luchei (The Origin of Cosmic Rays). — Izdatel'stvo AN SSSR. 1963.

11. Kaplan, S. A. and S. B. Pikel'ner. Mezhzvezdnaya sreda (Interstellar Space).—Fizmatgiz. 1963.

12. Ginzburg, V. L. and S. I. Syrovatskii. — Astronomicheskii Zhurnal, 40:466. 1963

DISCUSSION

G.M.Tovmasyan. According to the formulas of V.A.Kotel'nikov, the probability of detecting an extraterrestrial civilization is a function of the number of antennas used. A figure 10 was adopted in the calculations, and indeed we can hardly expect to tie up, say, 100 antennas with a surface of the order of $10^5 \, m^2$ for this purpose in the near future. However, if not 10, but only 5 ring telescopes are built, each with 20 small secondary reflectors, the probability of detecting an alien civilization will automatically increase by one order of magnitude.

V.A.Ambartsumyan. A few remarks on the artificiality criterion. Philosophically, I of course agree with the suggestion that Nature may repeat all that intelligent beings can do. However, the detection of natural radio waves resembling artificial signals in all particulars is in itself a remarkable event. This would probably point to the existence of extremely complex natural emission mechanisms. But civilizations are also a natural phenomenon which may generate these peculiar signals. Therefore, if a signal of this kind is detected, we must assume that it is either emitted by an extraterrestrial civilization or generated by some highly complex natural mechanism reminiscent of a civilization. I shall try to illustrate this line of thought by the following example.

Suppose that we have landed on some planet and the first thing we see there is a beautiful car. We of course may say that this car is a product of some natural process. If, however, we try to visualize this natural process, we inevitably come to the conclusion that it is very much like what we call a technological civilization.

Practically speaking, I think that already the condition of high mono-chromaticity (band width of the order of 1 c/s) is sufficient for the identification of an artificial signal. It is sufficient to supplement this powerful criterion by some simple test, say, rudimentary frequency modulation, to make the detection absolutely certain. The artificiality of signals can thus be detected without much difficulty.

E.G.Mirzabekyan. It seems to me that identification of artificial signals is no problem. As regards information, call signals themselves are a mine of information: they give notice of the existence of a trans-mitting civilization, and also indicate that this civilization is sufficiently advanced to try to establish contact with others. (After all, if somebody calls me in the street, it means that I have been recognized and that I am needed for some purpose.) This information is clearly of enormous scientific and philosophical importance.

E.E.Khachikyan. I would like to cast my vote in favor of starting transmission, and not only reception, of radio signals.

We do not know what is the exact stage of development of other civiliza-tions in the Universe. Now, if we do not start transmitting, the search

for signals from other civilizations may prove to be fruitless. After all, if each civilization regards itself as an inferior member, fitting for passive reception only, nobody will transmit. Therefore, we, as well as other civilizations, should immediately start transmitting if there is to be any hope of establishing communication on the cosmic scale.

P. M. Geruni. This is not the place to discuss the optimal antenna for establishing communication with extraterrestrial civilization, but since S. E. Khaikin stated unequivocally that the VPA is best suited for this purpose, while G. V. Tovmasyan devoted his entire paper to the merits of the two-reflector spherical antenna of ring geometry, I shall venture to remind the participants that there is also the large two-reflector antenna (LTA) which will probably prove to be very convenient for interstellar communication.

I. S. Shklovskii. Transmission of information to other civilizations is a fully understandable and justified project. At the New York World Fair, special containers were buried with certain material intended to convey information on present-day technology to our descendants in the far future. This undertaking in principle is not different from communication with alien civilizations. The only difference is the cost.

B. E. Khaikin. 1) Modern cybernetic machines are quite adequate for identifying and decoding artificial signals.

2) The problem of interstellar communication should be considered not only in terms of radio waves: we must not ignore telemetry, communication via gravitational waves, and possibly other means.

D. Ya. Martynov. After V. A. Kotel'nikov's paper, who presented us with a highly optimistic prospect of communication even with the farthest civilizations, we can permit ourselves the luxury of working with "softer" parameters than those assumed by Kotel'nikov: a longer integration time can be taken, more reliable signals can be picked up, and a comparatively certain decoding of information can be attained if the search is limited to smaller distances, say, 100 parsecs = 300 light years. In this sphere, the astronomers can easily select over a hundred potential communicants.

We should start with a humble beginning, and if the first plans prove successful, then after 10 years or so, when we have built new equipment, the probing can be extended to a larger sphere with a radius of, say, 1000 light years.

As regards differentiation of artificial signals from natural radio waves, none of the criteria proposed here is sufficient. And yet, regular repetition of signals according to some complex program, point-like nature of the source, monochromaticity, and, finally, circular polarization of the signal, when combined together, give a reliable indication of artificiality. It has been suggested here that "their" concepts of time may be radically different from ours, so that we may actually fail to detect the repetition of the signal. This does not constitute a real danger, since the frequency of the transmitted signals establishes an intrinsic time scale according to the relation $\Delta f \times \tau \approx 1$.

Fortunately, the frequencies of $10^9 - 10^{10} - 10^{11}$ c/s, where the noise is minimal, readily penetrate through the ionospheres of planets which are not exceedingly far from their primary, if these planets are not radically different from the Earth. Anyhow, to avoid the obstacle of denser ionospheres, the wavelengths should not exceed a few decimeters.

I also oppose noise spectra, but in my opinion extreme monochromaticity will only increase the probability of losing a detected signal due to the Doppler-Fizeau shift. In partifular, a signal sent from the Earth in the above frequency band will drift within ±1 Mc/s about the fundamental frequency due to the Earth's orbital motion. It remains to be seen whether enough energy can be pumped into this band. Specialists will have to decide on this point.

By studying the regular variation of the signal frequency, the receiving civilization will learn much about the planet from which the signal has been sent. After all, in the optical range, the shifts of spectral lines make it possible to determine the orbits of spectral binaries and the total mass of the system. Refined analysis of the signal will give the rotation period of the planet and its minimum size.

I. S. Sh k l o v s k i i . It should be kept in mind that monochromaticity alone is by no means a criterion of artificiality. For example, the powerful radio bursts on Jupiter are highly monochromatic and even periodic due to Jupiter's rotation about its axis. The bursts accompanying solar noise storms are also fairly monochromatic. In general, some cosmic objects can be expected to emit monochromatic radiation near the corresponding gyrofrequencies. The nearest stars, for example, may be surrounded by large planets, or so-called "invisible satellites" which emit nearly monochromatic bursts whose intensity is greater by a few orders of magnitude than the intensity of the Jovian bursts.

E. Ya. B o g u s l a v s k i i . The requirements of optimal signal filtration and limiting sensitivity suggest that smoothing should precede detection. It is therefore clear that the broader the signal spectrum, the greater the quantity of information needed for efficient filtration. And conversely, narrow-band signals can be detected against background noise without knowing much on the coding procedure employed. If other civilizations are also aware of all this, it is reasonable to look for monochromatic signals from space.

B. V. K u k a r k i n . Optimism is an excellent thing, but a measure of skepticism is required to help preserve the perspective.

Periodicity of signals does not provide a s i n g l e - v a l u e d proof of artificial origin. A great many periodic processes in nature are of clearly mechanical origin. Cepheids, for example, pulsate with a constant period for many decades. Some cepheids have been discovered with a period of a mere 80 min. Shorter-period cepheids apparently also exist. Our techniques for the detection of variable stars are not adapted for the discovery of objects with extremely short periods. We do not know as yet whether the luminosity pulsation of cepheids is accompanied by radio bursts. This is quite probable, since at the middle of the ascending branch of the cepheid's luminosity curve there is a brief conversion of a sound wave into a shock wave.

There are even more remarkable examples of periodicity in the optical region. For example, "previous" novae display slight, but strictly periodic fluctuations of brightness with periods of a few tens of seconds. And again we do not know whether this phenomenon has an analog at radio wavelengths.

The above examples are intended as a warning against including periodicity among the artificiality criteria: periodicity of physical characteristics is a very common natural occurrence in the Universe.

V. I. S l y s h . It seems that many of the participants are in favor of monochromatic signals. And yet it is hardly reasonable to suppose that the highly advanced type II and type III civilizations will only send monochromatic call signals. They will apparently try to transmit as much information as possible, and this clearly requires a broad frequency band.

We should therefore concentrate on point sources as the most promising candidates for artificiality.

V. S. T r o i t s k i i . I would like to emphasize that the technical requirements of the search for radio signals from other civilizations are unfortunately at variance with the fundamental requirements of radio astronomic research. The problem under consideration requires narrow-band spectral analyzers of high sensitivity. Radio astronomers, on the other hand, work with wide-band receivers. Of course, this applies only if the monochromatic signal is recognized as the most promising form of artificial radio waves. A suggestion has been made that noise signals should be transmitted, as this simplifies the search over the frequency band. We must remember, however, that for equal transmitter power in a broad frequency band or in a very narrow band (as those of the modern masers or quartz generators), the maximum signal-noise ratio in the receiver is obtained for a sinusoidal signal. Indeed, if the entire transmitted frequency spectrum is received, the sinusoidal signal permits the receiver passband to be reduced in the same proportion as the noise spectrum width to the "monochromatic" spectrum width. The set noise in the reception of the sinusoidal signal is reduced by the same factor. The effective signals, on the other hand, are equal in both cases, since the transmitter power is constant.

The signal-noise ratio and the range for a given transmitter power are thus maximal with a sinusoidal signal.

V. D. K o t e l ' n i k o v . I cannot accept S. E. Khaikin's suggestion that radio astronomic observations should be reduced to a search for extraterrestrial civilizations. Special observation programs and techniques are required, which cannot be improvised offhand.

The requirement that the transmitted signal should be highly monochromatic is apparently unacceptable either. Narrow-band transmission cannot be detected with the existing ordinary radiometers. As regards wide-band signals, which are identified with noise, the probability of detection is precisely equal to the probability of detection of monochromatic signals if we are aware of the fact that this is not random noise. If, however, the exact nature of the noise signal is not obvious, higher transmitter power is required. Non-noise signals should therefore be preferred. Another point: the information deposited in the signal is easily lost in narrow-band reception. Doppler shifts, however, can be measured with greater accuracy.

Artificiality criteria have been variously discussed here, ostentatiously for the purpose of dissociating artificial from natural signals. However, we are far from being able to form a comprehensive system of tests. Further studies are required.

As regards isotropic and beamed transmission, in my opinion scanning beams should be preferred.

On the subject of call signals, I would like to observe that the transmission of call signals is apparently a must. This substantially facilitates

the detection of the calling civilization. Call signals should probably be followed by a message, without waiting for a return signal from space.

In conclusion I would like to call your attention to the fact that astronomic, as well as radio astronomic, tools should be used in the detection of extraterrestrial civilizations and in communication with them.

LANGUAGES FOR COMMUNICATION
BETWEEN DIFFERENT CIVILIZATIONS
(synopsis)

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1. The first question to be considered is the probable contents of a message received from another civilization. It seems reasonable that this message should contain a presentation of a certain part of the sum total of knowledge available to the transmitting civilization. The decoding is therefore preferably begun at the most elementary stage of intelligence. We must, however, remember that different civilizations may command different knowledge, and that the differences may be pronounced even at the most elementary level. A p r i o r i, we cannot exclude the possible existence of a highly advanced civilization whose mathematics is essentially different from our fundamental mathematical concepts, or which has no analogous discipline at all.

These restrictions should not be attributed to a pessimistic outlook on the problem of message decoding as a whole.

2. Nothing can be said at present on the structure of languages for communication between civilizations. There may, however, be languages designed specifically for the purpose of communication with other civilizations, and their structure is best analyzed by considering how we would approach this problem were we to design a language of this kind. Freudenthal's LINCOS is a well known attempt in this direction. This language, in the words of its creator, is intended for communication with intelligent beings which are mentally not unlike man; it will hardly do in cases when the thinking processes and the fundamental concepts of the recipient are entirely different from ours.

The analysis of LINCOS, which according to Freudenthal is a "moderately formalized" language, reveals that a language for communication with extraterrestrial civilizations should be highly formalized, i.e., it should possess a highly unambiguous syntactic structure. An explicit description of syntax should preferably be included in the message; this part of the message may in fact prove to be the most convenient for the first stages of decoding. This proposition is based on the assumption that the use of language is the most probable common feature of civilizations which have reached the stage of mutual communication.

Other approaches of course are also possible: the first message may contain, say, images, and not concepts.

3. In conclusion it should be emphasized that for purposes of "linguistic qualification" in the event of communication with other civilizations, we should proceed not with the design of specialized "cosmic linguistics", but rather with the development of the general theory of language, without particular application to the problem of interstellar communications.

V. A. Ambartsumyan. I would like to stress that A. V. Gladkii's paper not only focused our attention on the problem of linguistic codes, but also on the problem of learning. These ultramodern aspects of pedagogical science unfortunately receive insufficient attention.

RESOLUTION OF THE ALL-UNION CONFERENCE ON EXTRATERRESTRIAL CIVILIZATIONS (BYURAKAN, 20−23 MAY 1964)

1. The problem of the existence and the evolution of intelligent life in the Universe is of enormous scientific and philosophical significance. Materialistic philosophy has firmly rejected the concept of anthropocentrism. Modern science clearly supports this point, but there is yet no actual proof of the existence of other civilizations on particular celestial bodies.

Communication with extraterrestrial civilizations will be of great importance for the natural sciences, philosophy, and man's everyday life. Until quite recently, interstellar communication was technically unfeasible, but certain precedents are known which suggest that special investigations and experiments will soon be staged with the purpose of establishing communication with extraterrestrial civilizations in the electromagnetic spectrum.

To ensure maximum range of communication and maximum information rate of signals, the interstellar communications should be confined to the frequency band of $10^9 - 10^{11}$ c/s (centimeter and decimeter wavelengths).

Modern radio equipment is adequate for the detection of signals over interstellar distances. On the other hand, the very fast development of cybernetics provides us with special tools for the investigation of the general laws of transmission and reception of information by extraterrestrial civilizations, for objective analysis of coded signals, and for a scientific approach to avarious problems of cosmic linguistics.

The rapid growth of scientific literature on the various aspects of extraterrestrial civilizations, the ever growing participation of scientists of different specializations in the study of this problem, and, finally, the first practical steps which have been taken in the USA in the direction of actual search for intelligent signals from space — all this indicates that the question of establishing communication with extraterrestrial civilizations has reached a stage where it can be regarded as a topical scientific problem which deserves regular attention.

2. It follows that a systematic experimental and theoretical investigation of the problem should be begun. The corresponding research program should provide for an all-sided, comprehensive analysis.

A. The experimental search for extraterrestrial civilizations should mainly follow two courses:

a) regular and systematic search for artificial signals from celestial objects within a radius of some 1000 light years and transmission of signals directed at the probable communicants in space;

b) search for signals from much more advanced civilizations by a detailed analysis of discrete radio sources whose properties suggest artificial origin.

97

To start work on these projects, it is advisable to combine the existing antennas into radio interferometers with very large bases, of the order of $10^6 - 10^7$ wavelengths in the centimeter range.

B. Optical observations conducive to the understanding of the problem of extraterrestrial civilizations should be extended. Under this category we include planetary and stellar cosmogony, search for planetary systems, identification of radio sources, and special extra-atmospheric observations.

C. More attention should also be devoted to the related subjects:

a) theoretical investigation of the statistical properties of artificial signals (development of artificiality criteria, development of methods for statistical differentiation of artificial signals from noise and application of these methods to the analysis of suspect sources);

b) development of methods for establishing communication and further improvement of cosmic linguistics on the basis of the general theory of language, and particularly the general theory of decoding, also making use of the theory of learning.

3. Special departments or research groups should be set up at certain scientific institutes and organizations (Shternberg State Astronomical Institute, Pulkovo Observatory of the USSR Academy of Sciences, Byurakan Observatory of the Armenian Academy of Sciences, Scientific Research Radiophysical Institute, Institute of Radio Engineering and Electronics, Siberian Department of the USSR Academy of Sciences, Department of Mechanics and Mathematics of the Moscow State University, etc.) which will concentrate on the problem of extraterrestrial civilizations and study different items of the general research program.

4. The Astronomical Council and the Council of Radio Astronomy of the USSR Academy of Sciences are requested to create a special coordinating and planning body — Committee on Interstellar Communications — with the following terms of reference:

a) to prepare for the next conference a program of search for artificial signals taking account of the special research groups in the Soviet institutes and organizations and the possibility of international cooperation and basing its recommendations on the entire volume of data collected by optical and radio observations;

b) to draw up during the years 1964 — 1965 a coordinated estimate of the material and technical resources required for the interstellar communications project, as it emerges from the reports and the discussions of this Conference, including the construction of special radio telescopes, radio receivers, and analyzing equipment. The members of the executive of the Interstellar Communications Committee, as proposed by the Conference, are listed in the Appendix.

5. It is the consensus of the meeting that the next Conference on Extraterrestrial Civilizations and Interstellar Communication should be held in 1965.

6. The Armenian Academy of Sciences is requested to publish the proceedings of this Conference in a separate volume.

APPENDIX

THE EXECUTIVE OF THE INTERSTELLAR COMMUNICATIONS
COMMITTEE RECOMMENDED BY THE
BYURAKAN CONFERENCE

1. I. S. Shklovskii — Shternberg Astronomical Institute, Moscow State
   University

2. V. S. Troitskii — Scientific Research Radio Physical Institute, Gorkii

3. G. M. Tovmasyan — Byurakan Observatory, Armenian Academy
   of Sciences

4. Yu. N. Pariiskii — Pulkovo Observatory, USSR Academy of Sciences

5. N. S. Kardashev — Shternberg Astronomical Institute, Moscow State
   University

6. L. M. Gindilis — Shternberg Astronomical Institute, Moscow State
   University

7. B. N. Panovkin — Council of Radio Astronomy, USSR Academy
   of Sciences